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A STUDY OF THE CAUSES OF VARIABILITY OF SPARK SPECTRA.

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THE variability of spark spectra, *i. e.*, the changes in the relative intensities of different lines, was noted by Kirchhoff, and has since been the subject of many researches.

Our present knowledge of the subject, though very incomplete, leads us to consider the causes of variability under the following heads:

1. *Temperature.*—The influence of change of temperature upon the relative intensity of lines was observed soon after the discovery of spectrum analysis. Being closely associated with other changes in physical conditions, especially in spark spectra, it is difficult to say how much of the variation observed may be ascribed to temperature alone. The view has been held that higher temperature most strengthens the lines of shorter wave-length, that it produces a shift of the maximum intensity of the spectrum. Kayser[1] has pointed out that this hypothesis can be applied only to lines originating from the same vibrating body, *i. e.*, to lines connected by a series relation; as on the other lines an increase of temperature may have the opposite

[1] ASTROPHYSICAL JOURNAL, 14, 313, 1901.

effect of reducing the intensity by destroying the more complex atomic aggregate from which these lines are derived.

2. *Vapor density.*—A change in the amount of luminous vapor produced may have a twofold effect. It may simply intensify all of the lines because of the increased number of radiating particles; or the strains produced by the greater crowding of the molecules may produce new vibrations and enhance only a part of those already existing. This is in accordance with the well-known fact that, in general, the diffuse lines are more affected by changes in the quantity of vapor.

3. *Electrical conditions.*—It is probable that these may affect the spectrum in very different ways. If oscillations are present, it is conceivable that they produce forced vibrations, strengthening some lines whose period is in some relation to their own. A change in the strength and frequency of the oscillations may be one effect of the introduction of self-induction. It may also produce a change in temperature, but it is an unsettled question whether the temperature is raised or lowered by self-induction. Oscillations may also intensify only the more damped vibrations. Capacity will impart to the spark discharges greater current strength, greater vapor density and probably higher temperature; but at the same time the period of oscillation is altered. A change of electromotive force changes the energy of the luminous particles, their velocity. Higher electromotive force may therefore strengthen the forced vibrations, but by increase of temperature the others also. The greater momentum of the molecules or ions, on the other hand, may help to disintegrate the more complex atomic aggregates.

It is clear, therefore, that altered electrical conditions may produce very great relative differences among spectral lines; but our very limited knowledge of the processes of production of light by electricity makes it difficult, or even impossible, to determine in each special case what effect of changed electrical condition has produced the observed change in intensity.

4. *Surrounding atmosphere.*—This may change the temperature, either by more or less of the electricity being conducted by the gas instead of by the metallic vapor, or through an alteration of

the potential between the electrodes. The same causes would affect the density of metallic vapor. Also, the gas may produce chemical actions, resulting in a change of temperature or of molecular structure.

As in nearly all cases a change in one condition is accompanied by a change in several others, it is extremely difficult to state the true cause of an observed change in intensity. Only by accumulating a great many observations with every possible change of conditions may we be able at last to determine some of the true causes.

My experiments, of which the account is to follow, have been concerned with changes given by self-induction in the spark circuit and by varying capacity; and the changes observed in the spectra probably resulted from a combination of the first three elements mentioned above. We should expect the chief alteration in electrical conditions by self-induction to be a reduction of the strength and frequency of the oscillations, with the reverse change when capacity is increased; though these changes in the circuit must result also in a difference in the interaction of primary and secondary, the effects of which are probably minor in their nature, but are obscure and depend on the construction of the induction coil used.

The metals studied were cadmium, zinc, magnesium, calcium, mercury, and aluminum. These are especially favorable for such work, each of them containing groups of related lines and other lines which are very sensitive to changed conditions. The effect of self-induction upon the spectra of some of these metals has been observed more or less extensively by Hemsalech,[1] Schenck,[2] Huff,[3] Néculcéa,[4] Berndt,[5] and Gramont,[6] and some of their results, especially in the way of throwing light upon the electrical processes in the spark, have been of much value in enabling me to form the conclusions toward which my own results point.

My photographs cover the region of the spectrum from

[1] Thesis, Paris, 1901.

[2] ASTROPHYSICAL JOURNAL, **14**, 116, 1901. [3] *Ibid.*, **12**, 103, 1900.

[4] *Comptes Rendus*, **134**, 1494, 1572, 1902; **135**, 25, 1902.

[5] *Ibid.*, **134**, 1048, 1205, 1902. [6] *Inaug. Dissert.*, Halle, 1901.

λ2100 to λ5700. They were taken with a small Rowland concave grating of 1m radius, giving a dispersion of 10 tenth-meters to 0.593mm. The inductance spool used was of rather fine wire, wound in a single layer, and immersed in oil for insulation. Its resistance was 8 ohms and its inductance 0.003 henry.

The general method of making comparison photographs was to time the exposures with and without self-induction, so as to make the lines least affected by self-induction of approximately the same intensity in the two photographs. The lines more affected would then usually appear in both photographs, and an estimate of the amount by which they were changed could be made with considerable accuracy. The changes considered are thus always relative to the lines least affected, as the weakened intensity of the spark by self-induction always required a longer exposure, the difference of the exposure varying with the metal used.

Leyden jars of 0.0027 microfarad each were used as capacity, with one small jar of 0.0018 microfarad. Both capacity and primary current remained the same in comparing the spark with and without self-induction, but varied for different elements. In comparing the changes given by large and small capacity, the same current was used in the primary for each, and the photographs were timed for favorable comparison in the same way as in testing the effect of self-induction. In some cases, when the same exposure was desired for photographs taken with varying capacity, a hand interrupter was used and the sparks counted, to avoid the change of period of the usual interrupter when the capacity was altered. A spark-length of about 2 mm was used throughout, and, except with calcium, did not change by an appreciable amount while the comparison photographs were being taken. An account of the experimental results follows.

CADMIUM.

The spark was produced between metallic terminals, and in order that the slight oxidation of the electrodes might not introduce an uncertainty in the comparison of two successive photographs, the spark was allowed to pass long enough to give some oxidation before a photograph was taken. The further oxidation

was so slight that it could scarcely make an appreciable difference in the rate of vaporization of the metal. This method seemed preferable to cleaning the electrodes before each photograph, as their removal for this purpose would make it impossible to keep exactly the same spark-length and an unchanged image on the slit.

Effect of self-induction.—The introduction of self-induction gives a means of separating the cadmium lines into two main groups, as has been done by Schenck.[1] The weakening action of self-induction is much greater upon "Group B" of Schenck's classification than upon "Group A," the "arc lines." I wish, however, to call attention to some special features in the differences produced by self-induction. My plates show, in the first place, that the lines belonging to the two subseries of Kayser and Runge are all included in Group A; while the prominent non-series lines, which are much more reduced by self-induction, are members of Group B. Further, the triplets of the first subseries are weakened more than the triplets of the second subseries, and this difference between the action on the two series is more pronounced as the wave-length becomes shorter.

Five times as long an exposure with self-induction as without was required to bring corresponding lines of the second subseries to the same intensity. The lines of the first subseries were then about three-fourths as strong as without self-induction,[2] especially noticeable in the triplets λλ2837, 2881, 2981, while the non-series lines λλ2573, 2749, 3250, 4216, 5490 retained about one-eighth of their former intensity, and the strong spark lines λλ5339, 5379 are quite blotted out by self-induction. These photographs are shown in Plate XXI (Figs. 1 and 2).

Effect of varying capacity.—With the same current in the

[1] *Loc. cit.*

[2] The comparison of intensities was assisted by the use of a photographic scale. This was made by moving a photographic plate beneath a narrow slit, with an incandescent lamp placed above at such a height that with two seconds' exposure the line on the plate was barely visible. Making each successive exposure 1.7 times the previous one gave a series of lines of increasing blackness. This scale was of much assistance in gauging the intensities of lines, though naturally the character of a line must be considered in estimating its intensity.

primary of the induction coil and no outside inductance, a comparison was made between the spectrum given with 0.0018 microfarad and that with 0.0027 microfarad capacity. Photographs so timed that the non-series lines were of approximately equal intensity in each gave the series lines only one-half as strong with the higher capacity, showing that the intensity of the non-series lines increases with capacity much faster than that of the series lines—the effect of increased capacity thus being opposite to that of self-induction.

In order to see if there is a rule governing this strengthening of the non-series lines by capacity, photographs were taken with one, two, four, and eight Leyden jars, with the same primary current and the same number of sparks for each photograph, this last condition being secured by a hand-interrupter. The chief attention in this comparison was given to the diffuse spark lines λλ5339, 5379, whose change in intensity could be closely estimated, and which were found by Schenck to be due chiefly to the oscillations in the spark. With such a number of sparks that these lines were barely visible with one jar, the increase for two, four, and eight jars was found to be, as nearly as could be judged, in the same ratio as the change of capacity. The series lines show a very gradual change, being about twice as strong with eight jars as with one. To eliminate the spark at "make," which appears with one jar and not with eight, when the same primary current was used, the spark-length was so adjusted that with four and with eight jars the spark came only at "break," and fewer sparks were used than before. These two photographs could be very accurately compared, and showed that with doubled capacity λλ5339, 5379 were intensified in the ratio 1 : 2, the first subseries triplet beginning at λ3404 in the ratio 3 : 4, and the second subseries triplet beginning at λ4678 in the ratio 4 : 5; showing the effect of increased capacity to be opposite to that of self-induction, both in general and for the two subseries.

Finally, two photographs were made with the same capacity (four jars), but with very different primary currents. The brightness of the spark was so greatly changed as to require fifteen times as long an exposure with the small current as with

PLATE XXI.

EFFECTS OF VARIED CONDITIONS ON SPARK SPECTRA.

FIGS. 1, 2, Cadmium. FIGS. 3, 4, Magnesium. FIGS. 5–8, Calcium.

the large, for the same average intensity of the spectrum. But little relative change could then be detected between the series and non-series lines, offering a striking contrast to the changes observed when a similar difference in the brightness of the spark was produced by increase of capacity. In this experiment we have a greatly increased vaporization, with probably only slight changes in the oscillations, indicating that the series lines are dependent on the vapor density in the spark rather than upon the electrical conditions; while both this and the results with capacity and self-induction point to the conclusion that the vibrations producing the non-series lines are favored by the peculiar conditions existing in the oscillations.

ZINC.

An exposure five times as long with self-induction as without gave approximately the same intensity for corresponding series lines, but the relative difference between the lines of the first and second subseries was greater than in the case of any other metal studied. Again it is the first subseries which is weakened as compared to the second. If the second subseries triplets beginning at λ 3018 and λ 4680 are brought to nearly the same intensity, the triplets of the first subseries beginning at λ 2757 and λ 3282 are rather less than one-half as strong with self-induction. Comparing the two triplets of the second subseries, the ultraviolet triplet shows the weakening effect of self-induction considerably more than the green triplet.

Turning to the non-series lines, we find λλ 2502, 2558, 4912, 4925 are very much reduced by self-induction, being changed more than any of the series lines. λ 4630 is little changed, while λ 3076 is relatively much strengthened. This action on the non-series lines is directly opposite to that noted by Crew[1] when the rotating zinc arc was surrounded by hydrogen. The effect of hydrogen was to intensify λ 2502 and λ 2558, and to weaken λ 3076. The diffuse spark lines λλ 4912, 4925 are more sensitive to the influence of self-induction than any other of the unrelated lines, and seem to belong entirely to the condensed spark, as

[1] ASTROPHYSICAL JOURNAL, **12**, 167, 1900.

Professor Crew does not mention them as appearing in the rotating arc.

Effect of varying capacity.—A change of capacity from 0.0018 to 0.0162 microfarad gives a relative difference between the first and second subseries directly opposite to that given by self-induction, and to about the same degree. The non-series lines λλ 3076, 4630 are weakened, and the lines λλ 2502, 2558, 4912, 4925 are strengthened by increased capacity; but the non-series lines are changed less by increased capacity than by self-induction, as compared with the series lines. The four lines last mentioned are enhanced by greater capacity to about the same degree as the triplets of the first subseries; while with self-induction these lines are weakened more than the triplets.

MAGNESIUM.

The spark was produced between pointed metallic electrodes of sufficient thickness to prevent melting. As in the case of cadmium, the electrodes were allowed to become slightly oxidized before a photograph was taken.

Effect of self-induction.—When corresponding lines belonging to the two subseries of Kayser and Runge were brought to approximately the same intensity (five times as long an exposure being required with self-induction as without), a group of lines could be at once selected which were very much reduced by self-induction relatively to the series lines. Considering only the stronger lines, this group consists of λλ 2791, 2796, 2798, 2803, 2916, 2929, 2937, 3892, 3896, 4481. The difference is greatest in the lines λλ 2929, 2937, 4481 (Figs. 3 and 4). The non-series lines λλ 2852, 4168, 4352, 4703 are changed but little by self-induction, except to be rendered sharper. λ 2852 is made blacker and the reversal is narrowed.

The lines of the first and more diffuse subseries are weakened by self-induction more than those of the second; but the change in corresponding lines of each subseries *is greater as the wave-length decreases.* For example, in the first subseries, the triplet at λ 3091 is more reduced than that at λ 3829; and in the second subseries the triplet at λ 3330 is weakened more than the green triplet at λ 5168.

Comparing Crew's[1] results with the rotating magnesium arc in hydrogen with the effect of self-induction on the spark discharges, we see that the three lines λλ 2929, 2937, 4481, which Crew found intensified by hydrogen, are greatly weakened by self-induction, the comparison in each case being with reference to the series lines.

Effect of varying capacity.—Comparing photographs taken with 0.0018 and 0.0162 microfarad capacity, the changes produced by increased capacity are in all respects the reverse of those given by self-induction. The lines most rapidly enhanced by increasing capacity are the three non-series lines λλ 2929, 2937, 4481. The first subseries triplets are strengthened more than those of the second subseries, and again the strengthening is most rapid in the region of shorter wave-length. If the exposures are so timed as to bring the green triplet λ 5168 to the same intensity in both cases, the ultra-violet lines of the same series are nearly twice as strong with large as with small capacity.

The shift of the maximum toward the greater wave-lengths seems to be the most definite evidence we have concerning the temperature change produced by self-induction, and indicates a lowering of the temperature by self-induction, with the reverse effect when capacity is increased, if the law governing the radiation of a solid body holds for a luminous vapor. The experiments of Langenbach[2] indicate that the radiation of gases in Geissler tubes follow this law, the hydrogen series lines of shorter wave-length being relatively intensified by conditions which should increase the temperature.

There has been much discussion concerning the origin of the arc and spark lines of magnesium. Schenck[3] showed that λ 4481 is due to the luminous "streamers" given by the oscillations, and it is the line most changed by self-induction. λλ 2929, 2937 are affected almost as much by altered electrical conditions, while the "arc lines," consisting of the series lines and a few others, apparently have vibrations which depend for their intensification upon the conditions attending increased vapor density. The differences between arc and spark spectra in general seem to rest upon a distinction of this sort.

[1] *Loc. cit.* [2] *Annalen der Physik* (4), 10. 789, 1903. [3] *Loc cit.*

The appearance in the arc of the distinctively spark lines seems to require abnormal conditions which probably approach those of the spark. The fact that with both magnesium and zinc the lines which Crew found changed by an atmosphere of hydrogen around the rotating arc suffer the greatest change by self-induction, and in an opposite direction, seems to offer additional evidence that the differences between the arc with one terminal rotating and the stationary arc are based on electrical changes caused by the constant interruptions, and not by a difference in temperature or vapor density in the two arcs. This unusual electrical action, as Hartmann[1] has pointed out, may be expected to arise from the rapid variation in circuit conditions given by the interruptions.

As to the action of hydrogen on the rotating arc, it would seem that much of the relative difference observed by Professor Crew might be ascribed to the vastly greater number of interruptions required in an atmosphere of hydrogen to give a photograph comparable to that taken in air. As Crew found the rotating magnesium arc in air to give λ4481 ten times as strong as λ4352, it follows that the reduction of the general intensity by hydrogen, necessitating a longer duration of the electrical conditions which favor λ4481, would result in an increase of the difference between these two lines. Another element to be considered is that if the hydrogen atmosphere decreases the vapor density of the arc, as is probable, then the group of lines which seem to depend upon vapor density, including the series lines and λ4352, would be weakened relatively to the spark lines λλ4481, 2937, 2929, which are favored by the strong electrical action.

If we accept the view generally held that hydrogen reduces the temperature of the arc, and also, as seems probable from my observations, that the temperature of the spark is lowered by self-induction, then the opposite effects of hydrogen and self-induction indicate that the spark lines of magnesium are not lines of high temperature. This agrees with the conclusion drawn by Hartmann[2] from the fact that λ4481 rapidly increases in relative intensity in the arc with very low current, indicating that the line

[1] Astrophysical Journal, 17, 270, 1903. [2] *Loc cit.*

is favored by the highly charged condition of the electrodes when the current is frequently interrupted, rather than dependent on temperature or vapor density.

CALCIUM.

The lines of calcium were found to be very sensitive to changes of circuit conditions. The spark passed between carbon electrodes moistened with strong calcium chloride solution. While this method did not insure a constant quantity of calcium in the spark, the relative differences could be reproduced at will, and were so pronounced that there seemed to be no uncertainty in ascribing them to the variations of self-induction and capacity.

Effect of self-induction.—Photographs favorable for comparison were given by an exposure one and one-half times as long with self-induction as without (Figs. 5 and 6). The lines separate into two groups, one of which is very much weakened by self-induction with respect to the other. This weaker group consists of the three line pairs λλ3159, 3179, 3706, 3737, 3934, 3969, having approximately the same difference in wave-number. Further, these pairs are weakened in quite different degrees. The ratio of intensities, with and without self-induction, of the pair of shortest wave-length is about 1 : 6, that of the next pair 1 : 4, and that of the H and K lines 1 : 2. The effect of self-induction is thus more pronounced as the wave-length decreases, *on lines which are probably related*—a result which again points to the conclusion that self-induction causes a reduction of temperature.

The lines of the second group, which are relatively strengthened by self-induction, include those belonging to the first and second subseries of Kayser and Runge, the strong line λ4227 and the unrelated lines in the region studied (to λ5603). These lines are all strengthened in about the ratio 3 : 1. The calcium-oxide band at about λ5525 also appears much stronger with self-induction. By this is not meant an *absolute* strengthening, as the exposures were so timed as to give an average between the two groups of lines.

Effect of varying capacity.—The two photographs (Figs. 7 and 8), taken with 0.0018 and 0.0027 microfarad, respectively, show the

effect of greater capacity to be in all respects opposite to that of self-induction. Comparing the three line pairs, that of shortest wave-length is more enhanced by capacity than either of the other pairs. The unrelated lines, including λ4227, are weaker in the photograph with large capacity in about the ratio 1 : 3, this being the degree to which they were enhanced, in the photograph taken with self-induction, while the change of the line pairs by capacity is by no means as great as that given by self-induction. Self-induction has thus a more pronounced effect, as compared with change of capacity, on the three line pairs than on the lines of the other group; corresponding to the effect noted in the case of zinc.

In classifying the calcium lines, then, the three line pairs must be considered as "spark lines," in the sense that they are favored by the electrical conditions in the spark rather than controlled by vapor density, as the other calcium lines appear to be. My observations of the calcium arc spectrum[1] agree with this view, as it was then shown that the series lines were changed more rapidly than the line pairs, both by the amount of calcium in the arc and by gases which appear to alter the vapor density. Again, Sir William and Lady Huggins[2] observed that when the amount of calcium in the spark is diminished, circuit conditions remaining the same, the line λ4227 becomes weaker much faster than the H and K lines. Further evidence in the same direction is the fact that the line pairs are relatively much stronger in the spark than in the arc.

MERCURY.

The spark passed between the surface of mercury in a dish and a pointed copper terminal above. In this way the spark was maintained of constant length, which is impossible if the upper electrode is of carbon, and only the two strong ultra-violet lines of copper appeared.

The results with self-induction for the most part verify those of Huff.[3] With about ten times as long exposure, with as without self-induction, the series lines were obtained of the same

[1] ASTROPHYSICAL JOURNAL, **18**, 129, 1903.

[2] *Ibid.*, **6**, 77, 1897; *Proc. R. S.*, **61**, 433, 1897. [3] *Loc. cit.*

intensity, and little, if any, relative difference appears between the lines of the two subseries. The non-series lines may be divided into three groups: (1) those which are much reduced by self-induction relatively to the series lines, as λλ2848, 3790, 3984; (2) those changed to about the same degree as the series lines, as λλ3022, 4078; and (3) the lines λλ5770, 5790, which are not in the region covered by my photographs, but which Huff found relatively much stronger with self-induction. The line λ2848 is reduced by self-induction more than any other line observed, and Huff noticed a rapid intensification of this line by increased capacity. Unlike the foregoing elements, the ultra-violet mercury lines do not seem to suffer greater changes than those of greater wave-length, which may indicate that the lines of this spectrum have little dependence on temperature.

ALUMINIUM.

Effect of self-induction.—In the case of aluminium, we again find the non-series lines greatly weakened by self-induction, as compared with the series lines. An exposure two and one-half times as long with self-induction as without served to bring corresponding series lines to nearly the same intensity. The first subseries line pair λλ3082, 3093 was slightly weakened relatively to the pair λλ3944, 3962 of the second subseries. The weaker pairs did not appear with self-induction. The non-series lines λλ2816, 3587, 3602, 3613, 4480, 4513, 4530 were all much reduced by self induction, traces of these appearing only near the poles, when they were not entirely blotted out.

Effect of varying capacity.—Comparing photographs taken with 0.0018 and with 0.0162 microfarad capacity, we find that the lines reduced by self-induction are in all cases strengthened by larger capacity, relatively to the series lines, and extend farther toward the middle of the spectrum. Also the first subseries pair is enhanced considerably faster by increased capacity than the pair of the second subseries.

RESULTS.

The conclusions from the foregoing work may be briefly summarized as follows:

1. The lines of each of the six metals studied may be divided into two groups.

2. The first group contains the series lines and some others. These lines appear to be dependent on the rate of vaporization of the metal rather than upon changed electrical conditions, and the vibrations which produce them are probably of a simple kind. They are reduced by self-induction and enhanced by capacity, but not more than would be explained by the change in vapor density.

3. The second group contains the lines for which no series relations are known. They are weakened by self-induction and enhanced by capacity much more than the lines of the first group, suggesting that the vibrations are more complex and require a stimulus other than mere vaporization, as many of these lines do not appear in the arc.

4. Self-induction and capacity have an opposite effect upon all lines.

5. Of the two subseries, the first is much more sensitive to all changes.

6. The weakening of the series lines is not in proportion to their strength, but the last members of a series are reduced by self-induction much more than the first members, and a shift of the maximum intensity toward greater wave-lengths is produced.

7. The effect of capacity upon series lines is to shift the maximum intensity toward shorter wave-lengths, giving the greatest enhancement to the last members of a series.

I take pleasure in expressing my hearty thanks to Professor Kayser for his kindly interest and frequent advice during the progress of the work.

BONN,
January 1904.

SECONDARY SPECTRA.

By P. G. NUTTING.

SINCE early in the development of spectroscopy[1] it has been known that some of the elementary gases electrically excited give two entirely different spectra. One of these, called by Plücker and Hittorf the *primary* spectrum, usually consists of a large number of broad lines, well distributed over the whole visible and neighboring ultra-violet spectrum. The secondary spectrum, on the other hand, consists usually of but few lines, and these very prominent. It is the spectrum obtained when capacity is connected in parallel with the tube. The two spectra are easily obtained with an ordinary Plücker tube, having not too long nor too fine a capillary, and containing nitrogen, sulphur, or iodine vapor at a pressure of 2–10 mm. With a large condenser in parallel such a tube shows a secondary spectrum; without the condenser it shows the primary spectrum, if the current be not excessive. Some gases which exhibit secondary spectra also show anode and cathode glows having quite different spectra. With mercury vapor, however, the anode and cathode spectra are practically identical, and neither differs greatly from the spectrum obtained when a large condenser is placed in shunt circuit. The present investigation was undertaken to separate, in the Mendeleef system, those elements which show multiple spectra from those that do not, and to determine what conditions govern the production of secondary spectra.

Starting with the seventh group of the periodic system, it was found that chlorine, bromine, and iodine, all of the group that could be worked with, gave multiple spectra. The effect is particularly striking with bromine and iodine. Likewise, all of the sixth group available gave multiple spectra, namely, oxygen, sulphur, selenium, and tellurium. In the fifth group,

[1] PLÜCKER and HITTORF, "On the Spectra of Ignited Gases and Vapors, with Special Regard to the Different Spectra of the Same Elementary Gaseous Substance," *Phil. Trans.*, **155**, 1–29, 1865.

nitrogen, phosphorus, and arsenic exhibit multiple spectra, while bismuth does not. With arsenic, however, the primary (anode) and secondary spectra have two prominent green lines in common. In the fourth group, only the more metallic elements tin and lead could be used in a Plücker tube. The spectra of these were found not to change on connecting a condenser in shunt. In the third group, aluminium, indium, and thallium; and in the second group, magnesium, zinc, cadmium, and mercury, give only line spectra which are not essentially altered by capacity in parallel. Hydrogen excepted, the first group shows only single spectra. Without taking up the much-discussed[1] question of the rôle of water vapor in gas conduction, from the point of view of multiple spectra the evidence is very strong that the fine-line spectrum of hydrogen is a true primary spectrum, while the four-line spectrum is a true secondary. The latter is relatively enhanced under the same conditions that bring out the secondary spectra of other multiple spectra elements. The primary and secondary spectra of other elements, notably chlorine and bromine, may be made to coexist in the same way, and the presence of water vapor certainly favors the preponderance of the secondary spectra of other elements as well as hydrogen. Oxygen and sulphur are striking examples.

In the helium group there are wide differences. Helium itself shows but a single spectrum. Anode and cathode glows give identical spectra, and both remain practically unchanged on the passage of the condenser discharge. Argon, however, shows at least four widely different spectra. The red primary (anode) and blue secondary spectra have been described by several observers.[2] But the cathode glow shows quite a different spectrum from the anode (capillary) glow. With low dispersion it appears nearly continuous in the yellow, green, and blue, while the strong red line and the violet group of the anode glow are lacking. When the blue condenser discharge is produced

[1] CALLENDAR, *Nature*, **56**, 624, 1897. TROWBRIDGE, *Phil. Mag.*, (6) **2**, 370, 1901. LEWIS, *Phil. Mag.*, (6) **3**, 512, 1902. PARSONS, ASTROPHYSICAL JOURNAL, **18**, 112, 1903.

[2] TROWBRIDGE and RICHARDS, *Phil. Mag.*, (5) **43**, 77–83, 1897. KAYSER, *Berlin Akad.*, 1896. TRAVERS, *Experimental Study of Gases*, 1901, p. 312.

in the capillary, there is a buff-colored glow in the bulbs at either end. The spectrum of this glow shows the blue group lacking, but the yellow group of the red primary anode spectrum present. This difference between bulb and capillary spectra can hardly be regarded as other than a current density effect, since this is the chief, if not the only, difference in the excitation. As we should expect, the bulb spectrum with condenser is intermediate between the capillary spectrum with condenser and the red capillary spectrum without condenser.

The tubes of helium and argon for these tests were loaned by Professor Monroe, of Columbia University. Of neon, krypton, and xenon only the spectra of the two latter are said to be seriously affected by the condenser discharge.[1] No differences between anode and cathode capillary and bulb spectra appear to have been recorded.

In the accompanying abridged Mendeleef table the elements showing multiple spectra are separated by different type from those that do not. Elements showing distinct anode and cathode spectra are bracketed.

O	I	II	III	IV	V	VI	VII
	H						
He	Li	Be	**B**	**C**	(**N**)	(**O**)	**F**
Ne	Na	Mg	Al	**Si**	**P**	**S**	(**Cl**)
(**A**)	K	Ca	Sc	**Ti**	**V**	**Cr**	—
—	Cu	Zn	Ga	Ge	**As**	**Se**	**Br**
Kr	Rb	Sr	Y	Zr	**Nb**	**Mo**	—
—	Ag	Cd	In	Sn	Sb	**Te**	**I**
Xe	Cs	Ba	La	Ce	Di	—	—
—	Au	Hg	Tl	Pb	Bi	—	—

Excepting then the anomalous helium group and questioning hydrogen, we may say that in general, so far as observations go, *the acid-forming elements have multiple spectra*, while metallic elements do not. Near the dividing line primary and secondary spectra are nearly alike; the primary spectrum is heavily lined, and adding a condenser affects it but slightly.

The heavily banded primary spectra of sulphur and iodine suggest a classification on the basis of monatomic or polyatomic

[1] BALY, *Chem. News*, **88**, 26, 1903.

character. And we might expect an atom bound with several others in a molecule to radiate energy of more different periods than a free atom. But the behavior of nitrogen, argon, and xenon contradicts this view, and the behavior of compounds like water and *HgS* vapor strongly indicates that even iodine and sulphur are completely dissociated by the current when they become luminous.

Why should a condenser discharge produce a secondary spectrum? The oscillation frequency of a condenser is so much less than the frequency of collision of an electron in a gas at 1 mm pressure[1] that an electron must collide a great number of times before the impelling force is reversed. Hence the oscillatory nature of the discharge *per se* could have little effect on the spectrum of a gas. On the other hand, the current density during discharge is thousands of times as great as during the steady flow of the same current. Trowbridge has shown (*loc. cit.*) that an increase in current density alone is sufficient to change the red glow of argon into the blue glow characteristic of the condenser discharge.

In testing other gases for the effect of excessive current density, specially designed Plücker tubes were used. One form had a very fine (thermometer) capillary and hollow cylindrical electrodes; another had a third bulb interposed in the middle of the capillary. In this way the current density could be made a hundred or a thousand times as great in parts of the tubes as in others. Bromine, iodine, and hydrogen easily show the current density effect within the range of current that a common glass tube will carry. The primary spectrum changes continuously over into the secondary spectrum as the current is increased. Nitrogen and the sulphur group failed to show the secondary spectrum with the largest steady currents that glass tubes could carry. Argon is so sensitive to changes in current density that, in conjunction with a pocket spectroscope, it might be used as a milliammeter. Excessive current in a gas means excessive excitation of the radiating particles. If an electric current is a convection of the charged parts of atoms, and luminous and

[1] DAVIS, *Phys. Rev.*, 17, 501–505, December 1903.

ultra-violet radiation is caused by the vibration of these charged parts within the atom, we have a simple explanation of the effect of excessive current in producing secondary spectra. When the excitation is the feeblest that will produce luminosity, we should have but a single electron torn from an occasional atom by the passage of the current. With increased current, electrons would be torn from a larger percentage of the atoms; we should still have the primary spectrum, but more intense. But with excessively great currents, we should expect, not one, but several electrons to be torn from each atom. The remainder of the atom would have greatly altered modes of vibration, and we should expect the secondary spectrum actually obtained. The free electrons would radiate as moving charges between impacts, and, if impacts were frequent, would seriously interfere with atomic vibrations. Hence an excessive current should produce widening of spectral lines and a faint continuous background. A still further increase in current density in any gas would produce a continuous spectrum, a result already realized by Trowbridge by sending a powerful condenser discharge through hydrogen in a quartz tube.

It is difficult to get beyond mere speculation in connecting multiple spectra with acid-forming or polyatomic character, or with high valency. It appears to be easier to tear electrons from metallic than from non-metallic atoms. For this reason alone it may be possible to excite non-metallic atoms so feebly as to give a primary (whole atom) spectrum, while with metallic vapors we get only a secondary spectrum with the feeblest current that will produce luminosity. Two other significant and quite general properties of primary spectra may be noted. Primary spectra, perhaps without a single exception, become less banded and more strongly lined in character for the shorter wave-lengths. Again, primary and secondary spectra differ less in the ultra-violet than in the visible spectral regions. Both of these facts indicate that the more quickly moving electrons have greater freedom of motion within the atom, and that their motion is less interfered with by impact. The most characteristic, definite, and invariant portion of the elementary spectra appears to

be that lying between wave-lengths 200 and 350 $\mu\mu$. This portion should prove most useful in identifying elements, just as the infra-red spectra are characteristic of substances and molecular structure in general.

Only a few substances show markedly different spectra in anode and cathode glows. Nitrogen, oxygen, argon, and chlorine are the only ones whose anode and cathode glows are noticeably different in color. Bromine and iodine in Plücker tubes show slight differences, both in general color and spectra, between capillary (anode) and cathode glows; but these differences appear to be due entirely to differences in current density. Not one of the sixteen metallic vapors examined showed any differences either in color or in their spectra, nor do any of the acid-forming elements, aside from the three mentioned. The only general statements we can make regarding these elements that do exhibit differences in anode and cathode spectra are that they all belong to the class of elements showing both primary and secondary spectra, and that they are all of low atomic weight.

The three spectra of nitrogen have been studied in some detail by Lewis.[1] Oxygen presents still more interesting features. Anode and cathode are both line spectra, having but one prominent (red) line in common. The secondary (spark) spectrum is like the anode in the red and yellow, and like the cathode spectrum in the blue and violet. Secondary and anode spectra have four prominent lines in common; secondary and cathode, six. The differences in chlorine are not marked; in argon they appear to be all due chiefly to differences in current density.

It is difficult to account for spectral differences at anode and cathode. To be sure, the excitation is probably quite different in character in the two regions; but why should the atomic modes of vibration be altered even then? If, at the cathode, the atoms of the gas are set in vibration without disruption by the projected negative electrons, the cathode spectrum should resemble the primary. If, on the other hand, there is atomic

[1] Astrophysical Journal, 17, 258–269, May 1903.

disruption in the cathode glow, the cathode spectrum should resemble the true secondary, and could be imitated by increasing the current density in the anode glow. Further study of the remarkable multiple spectra of oxygen may throw light on this point.

NATIONAL BUREAU OF STANDARDS,
Washington, D. C.
February 1904.

ON A POSSIBLE VARIABLE RADIAL VELOCITY OF LONG PERIOD.

By H. C. Lord.

In the fall of 1901 a number of spectrograms of η *Piscium* were secured. Four of these were measured at that time, but, for reasons to be given later, were not reduced until a few months ago. These four plates gave as the mean velocity +21.9km per second. Upon reobserving the star this fall, I was surprised to find that the first plate secured, No. 827, gave a velocity of only +13.7km per second. Thinking that this might be due to a bad plate—for No. 827 was badly underexposed—I secured five more spectrograms, which gave as a mean for 1904 +12.3km per second. This variation, if real, is one of considerable interest, and I take this opportunity to bring this star especially to the notice of those engaged in the measurement of motion in the line of sight.

In view of the importance of the subject, I shall give a more complete history of these observations than would ordinarily be done. After several years' experience with the battery of two dense 60° prisms in photographing stellar spectra for motion in the line of sight, I was led to believe that better results could be secured with three light flint prisms, carefully designed. After a number of preliminary experiments, such a battery of three prisms was added to our equipment. The optical work was by Brashear, and the mechanical work, owing to a lack of funds, I was obliged to do myself. The three prisms are fixed in the position of minimum deviation for $H\gamma$. The collimator beam is 25mm in diameter. The prisms increase in size so as to transmit a clear beam of 30mm diameter between wave-length limits of 4600 and 4100 approximately. The prism angles are 62°54′ and the index of refraction for $H\gamma$ is about 1.64. The camera has a focal length of about 380mm. The linear dispersion on the photographic plates is such that one one-thousandth of a

millimeter corresponds to a velocity of 1.4km per second at $H\gamma$.

The performance of these prisms is most satisfactory. In order to test them, the star η *Piscium* was selected as being as faint as I could hope to get, its photographic magnitude as given in the *Draper Catalogue* being only 5.02. The diameter of the objective of the equatorial at this observatory is only 12.5 inches, and we are located within the limits of a city of 150,000 population where soft coal is used extensively. Satisfactory spectrograms were secured in sixty minutes, although exposures of from seventy-five to ninety minutes were generally given.

This equipment was finished in the fall of 1901, and four spectrograms of η *Piscium* were secured and measured, but not reduced, as a slight source of error was detected in the hydrogen comparison spectrum; but as both hydrogen and iron were used, no appreciable error could have been introduced in the resulting velocities, as is completely proved by observations made on other stars taken after this error had been eliminated. Much time was then spent in devising a scheme whereby the measures of such plates could be easily, rapidly, and rigorously reduced by the method of least squares. This method I hope to give in detail at another time; suffice it to say that all plates are measured with violet end left and violet end right, and the measurements separately reduced by the method of least squares.

By the spring of 1902 the work was nicely started, when it was again interrupted for nearly a year by the addition to the observatory of a large amount of apparatus, including several buildings, for purposes of instruction. During this time Mr. B. F. Maag came to this observatory as assistant, and as soon as he was satisfactorily trained, all the work of measuring and reducing the plates was intrusted to him. In every case, however, the photographs were taken by myself. A considerable number of duplicate measures of the same plates made both by Mr. Maag and myself show practically no systematic differences.

Work was again started during the summer of 1903, and in getting up back work the old measures of η *Piscium* were reduced with the following results:

Date	Plate No.	Velocity Reduced to Sun	Measured by
1902			
Jan. 1.....	672	+20.0	Lord
4.....	674	+20.7	Lord
6.....	677	+21.1	Lord
10.....	679	+25.4	Lord

The mean of these results gives +21.9km per second.

In order to have five separate determinations on each star, I undertook to reobserve *η Piscium* this fall. Great difficulty was encountered in getting a good plate. Twelve ninety-minute exposures were made before one, even though badly underexposed, was deemed suitable for measurement. I attributed this trouble first to the sky, then to the plates; but the chief cause of trouble was not discovered until after Plate 827 had been taken. It was then found that, for some unexplained reason, the focus of the large objective for $H\gamma$ had changed by about 2mm. This was corrected; and from that time on, with new plates, not a single exposure was lost when the sky was even in a fair condition.

Plate 827 gave a velocity of +13.7km per second—a change of about 8km per second from those two years earlier. It was seen at once that more work was needed. Mr. Maag then remeasured Plate 679, with a result of +24.5, as against +25.4 measured by Lord. An old plate, No. 662, taken December 15, 1901, was hunted up and measured by Mr. Maag, with a result of +18.5km per second, making the mean for that year +21.1.

The following additional plates were secured:

Date	Plate No.	Velocity Reduced to Sun	Measured by
1903			
Dec. 7.....	831	+17.0	Maag
13.....	835	+10.6	Maag
15.....	837	+ 9.4	Maag
22.....	841	+12.7	Maag
1904			
Jan. 9.....	842	+10.6	Maag

After this date the star was too near the Sun for observation.

The above results, together with Plate 827, give as the present

velocity of this star +12.3 km per second—a change of 8.8 km per second in two years. Collecting these results, we have:

1901 and 1902: mean velocity, +21.1; maximum measurement, +25.4; minimum measurement, +18.5.

1903 and 1904: mean velocity, +12.3; maximum measurement, +17.0; minimum measurement, +9.4.

Plate 662 was probably not measured in 1901, as I am under the impression that the diaphragm which covers the more intense comparison lines during the greater part of the exposure was not then in place. The variation *inter se* of these measures is somewhat large, but not excessive, I think, in view of the instrumental power at my command. They are, however, larger than we get ordinarily. This may be due, however, to the low magnitude of *η Piscium*.

The exposures never exceeded ninety minutes.

I give below a complete table of results:

Plate No.	Date of Photograph	Observed Velocity			Reduct. to Sun	Vel. Red. to Sun	No. Lines V. L.	No. Lines V. R.	Measured by
		V. L.	V. R.	Mean					
662	Dec. 15, 1901	+45.1	+42.9	+44.0	−25.5	+18.5	14	14	Maag
672	Jan. 1, 1902	+50.3	+47.6	+49.0	−29.0	+20.0	23	23	Lord
674	4,	+52.8	+47.4	+50.1	−29.4	+20.7	20	20	Lord
677	6,	+52.5	+48.7	+50.6	−29.5	+21.1	14	15	Lord
679	10,	+56.1	+54.3	+55.2	−29.8	+25.4	18	17	Lord
679	Second measure	+54.6	+53.9	+54.2	−29.8	+24.4	12	12	Maag
827	Nov. 26, 1903	+35.1	+29.7	+32.4	−18.7	+13.7	13	13	Maag
831	Dec. 7,	+40.1	+39.4	+39.8	−22.8	+17.0	13	13	Maag
835	13,	+35.6	+35.0	+35.3	−24.7	+10.6	18	18	Maag
837	15,	+36.4	+33.1	+34.8	−25.3	+ 9.5	13	13	Maag
841	22,	+41.1	+38.4	+39.8	−27.0	+12.8	12	12	Maag
842	Jan. 9, 1904	+42.1	+38.7	+40.4	−29.8	+10.6	12	12	Maag

In all cases *Hγ* and thirteen carefully selected iron lines are used for comparison.

That the above observations represent a real change in velocity, and are not simply errors of observation, I am led to believe from the following considerations:

1. The spectrum of *η Piscium* is well suited to spectroscopic measurement, containing many well-defined solar lines, being classed as Type XIV*a* by Miss Maury.

2. Observations of *Venus* in 1902 gave as the mean of ten residuals, seven taken just after sunset and three just before sunrise, in the sense C.−O., −2 km per second.

3. The close agreement of the work done here with that of other observers, as the following table will show:

Star	Campbell	Wright	Vogel	Scheiner	Frost and Adams	Lord
α *Cassiopeiae*....	− 4.3	.....	−14.9	−15.6	.....	− 0.6 in 1897 − 2.6 in 1903 − 0.4 in 1898
α *Arietis*	−14.1	.....	−14.5	−14.9	−13.7	−12.5 Oct. 1903
ε *Pegasi*.....	+ 5.7	.....	+ 7.3	+ 8.6	+ 6.1	+ 6.2 Sept. and Oct. 1903
ε *Leonis*.....	.....	+5.1	.....	.....	+ 5.5	+ 7.8 Mar. and Apr. 1898
α *Ursae Majoris*.	− 9.8	.....	−10.3	−12.7	.....	− 5.4 Apr. 1902
α *Boötis*.....	.....	.....	− 7.0	− 8.3	− 4.8	− 4.0 " 1902
ι *Aurigae*	.....	.....	.....	.....	+19.0	+20.8 Feb. 1898

In addition to the above, two plates of η *Boötis* taken in 1899 gave a mean of +13.0 km, and five taken in 1902 gave a mean of +12.0 km per second. Furthermore, of two plates of δ *Cephei*, one taken August 24, 1903, gave −22.7 km, and one taken August 25, 1903, gave −6.0 km per second, though at that time neither Mr. Maag nor myself knew it was a spectroscopic double.

The data of the above table in the case of Campbell, Wright, and Frost and Adams are taken from papers published in the ASTROPHYSICAL JOURNAL; in the case of Vogel and Scheiner, from Frost's Scheiner's *Astronomical Spectroscopy*.

In conclusion, I wish to acknowledge my indebtedness to my assistant, Mr. Maag, whose care and enthusiasm in the laborious work of measuring and reducing the plates have contributed much to the value of these observations.

EMERSON MCMILLIN OBSERVATORY,
Columbus, Ohio,
February 9, 1904.

ON THE INVARIABILITY OF THE WAVE-LENGTHS IN THE SPARK AND ARC SPECTRUM OF ZINC.[1]

By J. M. EDER and E. VALENTA.

THE width of the lines in the arc and spark spectrum is a complicated and, at present, little-understood function of the temperature, pressure, and density of the luminous vapor (H. Kayser[2]), and is probably dependent on the nature of the electrical stimulus and the dielectric (Hartmann[3]). The experimental observations of the phenomena of the broadening of the lines have so far by no means reached a final conclusion. In particular, the question is undecided whether or not the maximum of intensity—in a sense the center of gravity of a line—is displaced as the line broadens, a question of fundamental significance for all branches of spectroscopy.

Humphreys and Mohler[4] have demonstrated beyond doubt that actual displacements of spectral lines, as clearly evident changes of wave-length occur as a result of variations of external pressure. F. Exner and E. Haschek, however, went decidedly farther, and stated that these displacements occur more strongly in the spark than in the arc, and depend not only on the external atmospheric pressure, but also on the partial density of the vapor concerned.[5] They stated further that many spark spectra exhibit considerable shifts of lines as compared with the same lines in the arc (in both cases at ordinary external atmospheric press-

[1] Translated from the *Sitzungsberichte der K. Akad. der Wiss. in Wien*, Math.-Naturw. Klasse, **112**, II*a*. Communicated at the session of October 22, 1903.

[2] *Handbuch der Spectroscopie*, **2**, 296, 1902.

[3] *Sitzungsber. der K. Akad. der Wiss. zu Berlin*, 1903, 40 and 234.

[4] ASTROPHYSICAL JOURNAL, 1896 and 1897. They raised to several atmospheres the pressure of the gas within which the arc was produced, and observed the displacement of the different spectral lines toward the red, and thus found that the increase in wave-length is proportional to the pressure of the surrounding gas.

[5] EXNER and HASCHEK, *Wellenlängentabellen für Spektralanalytische Untersuchungen*, Leipzig and Wien, 1902, p. 13.

ure[1]), attempting to explain it by pressure effects in the spark, and they tried to calculate the pressure in the spark from the amount of these displacements. Haschek and Mache[2] sought to demonstrate directly the pressure in the spark, but obtained no agreement between the observed values and those computed from the "displacements." Later Haschek concluded from his further experiments[3] that different laws hold for displacements in the arc from those in the spark, so that it is not permissible to compute the pressure in the spark from the displacements of the lines. The pressures observed by Haschek accord so badly with the computed values that he himself says: "The computed pressures are so greatly different from each other that it cannot be doubted that the displacements of the lines are determined by other causes." He suggests as such another cause of the "shifts" "the increasing density of the luminous vapor;" with equal increase of vapor density the displacement is supposed "to be greater for the spark than for the arc lines." Thus, for instance, the zinc lines at λλ 3282, 3302, 4680, 4722 are said by Haschek to have a wave-length greater by from 0.03 to 0.16 tenth-meters in the spark than in the arc. In other cases Haschek cites shifts of as much as 0.2 tenth-meter for spectra with many lines, and up to 0.07 tenth-meter for spectra with few lines. These are very considerable quantities, and far beyond the allowable limits of error for grating spectra. As evidence of the correctness of these observations he adduces numerous measures of wave-lengths (with different elements, as *Al*, *Zn*, *Ca*, *Si*, *Zr*, *Cr*, *Ti*, *Ce*, *Va*, etc.).[4] These data gave the impression that the existence of relative shifts between spark and arc lines at ordinary atmospheric pressures was certainly established. According to Haschek, the quantity of vapor had a demonstrable effect on the actual wave-length of lines, so that in his opinion *a method of quantitative spectrum analysis could be based on the measurement of these so-called*

[1] No reference is made in this paper to displacements of lines caused by a rapid motion of the source of light in the line of sight according to Doppler's principle, which is used for measuring the radial velocities of stars.

[2] *Sitzungsberichte, Wien*, 1898. [3] *Ibid.*, **110**, IIa, 181, March 1901.

[4] Meanwhile N. A. Kent demonstrated that for titanium lines Haschek's shifts of 0.13 tenth-meter do not occur. ASTROPHYSICAL JOURNAL, **17**, 286, 1903.

shifts of lines.[1] For instance, the wave-length 4722.510 was held to be accurate for pure zinc (spark spectrum), while for a 5 per cent. zinc alloy used as electrode the wave-length was only 4722.399. Thus the partial density in the luminous vapor would be of decisive influence on the wave-length.

The doctrine of the dependence of the wave-length of the spectral lines upon the partial density of the vapor under examination is given a position of prime importance in the work by Exner and Haschek entitled *Wellenlängentabellen für spektralanalytische Untersuchungen auf Grund der ultravioletten Funkenspektren der Elemente* (Leipzig and Wien, 1902, Teil I, p. 13). We might well concede to the extensive numerical data they offer as the result of their measures of wave-lengths an indisputable weight of evidence, if we were able to suppress our well-founded suspicion of the value of their photographic material as evidence.

In case of the spark spectra of calcium and lithium, we obtained on an earlier occasion results not in accord with the statements cited, as we then accurately demonstrated (pointing out that errors of a photographic nature doubtless were involved);[2] and when we recently began measurements on the spectrum of zinc, we again met with experimental results contradictory to the statements of Haschek. Similarly, our findings as to the spectra of alloys with large and small proportions of zinc contradict the statements and measures of Haschek.

Objections to the statements of Exner and Haschek were also made by H. Kayser,[3] of Bonn, who had never observed an effect of the quantity of the element present on the wave-length in his investigations of arc spectra. In his opinion, the partial pressure of the vapor in the arc produces no shifts, as may be readily demonstrated if apparatus of high resolving power is employed, but otherwise apparent shifts may occur. As to the relation between spark and arc wave-lengths and the effect of the partial

[1] *Sitzungberichte, Wien*, **111**, IIa, 232, February 1902.

[2] "Ueber das Funkenspektrum des Calciums und Lithiums und seine Verbreiterungs- und Umkehrungserscheinungen." *Denkschriften der Akad. der Wiss. Wien*, **67**, 1898.

[3] *Handbuch der Spektroscopie*, **2**, 297, 308, 309, 310.

pressure on shifts in the spark spectrum, no experimental confirmation has so far appeared from other sources for the assumed shifts of Exner and Haschek.

It must be expressly remarked here that the question involved is not that of the breadth of the lines in the so-called unsymmetrical broadening, which has been known for years, and which is exhibited, among other ways, when the lines from pure metallic electrodes (as zinc, lead, etc.) are strongly widened toward the red in the spark with large capacity, while they become quite sharp if the metals are present in the vapor as small impurities of the electrodes (hence with slight partial pressure). We are, on the contrary, in this displacement phenomenon of Exner and Haschek concerned with the precise wave-length of the maximum of intensity of the lines, which in a sense represents the center of gravity of the lines.

If we base such measurements upon the maximum of intensity of the lines in question, which at present is the only admissible and generally adopted procedure, as was also recognized by Haschek,[1] we arrive at results contradictory to the statements of Haschek when the photographic work is done correctly and the proper degree of resolution is employed for the spectra.

We first selected the spark and arc spectra of zinc, and occupied ourselves for a long time exclusively with eight zinc lines which might be regarded as typical, and which were brought forward by Haschek, along with other similar spectra, as furnishing especially strong evidence in support of his theory.

Our large Rowland concave grating of fifteen feet radius[2] is an excellent one, and was pronounced by H. Kayser, of Bonn, who saw our spectrum photographs, to be of the very highest grade. Now, the possibility of surely finding the maximum of intensity of unsymmetrically broadened lines—and Haschek's investigations deal with these alone—depends upon limiting as much as is practicable the extent of the broadened and diffuse portions of the lines by careful photographic procedure. We

[1] *Sitzungsberichte, Wien*, III, IIa, 232, 1902.

[2] That is, of the same radius as the grating employed by Exner and Haschek.

worked with a slit having sharp steel jaws at a width of from 0.008 to 0.03 mm, and obtained a good degree of sharpness of the lines at the latter width. We determined the true photographic focus of the grating by empirical settings at each half-millimeter,[1] and bent the photographic plate (on mirror glass) to the focal curve of the grating. We effected the superposition of the lines by means of a light diaphragm which could be moved up and down in front of the plate-holder; by the motion of the diaphragm each line could be photographed in three parts, one after another. At every exposure the whole grating was fully illuminated. The exposures were short.

Agreement has hitherto been lacking as to what constitutes a "short exposure" or "minimum exposure" with the best degree of sharpness and delicacy and with correct development. Until such agreement is secured, differences in observations of the so-called shifts of the spectral lines will occur—as have been repeatedly described by Haschek in contradiction to other spectroscopists—and self-deceptions will be difficult to control. In order to give some definite data as to the sharpness of lines, the observer should not only specify the width in tenth-meters of the lines measured, but should also state the degree of "blackening" for questionable lines on the particular negative, which blackening should be quite slight. It might, indeed, be made a criterion as to whether a photograph answers the most rigorous requirements if an unsymmetrically broadened line was obtained with a certain minimum width for an average or for a most delicate degree of blackening. We measured the width of the sharp iron lines of the arc, obtained with a favorable arrangement of the apparatus, and found they were from 0.03 to 0.04 mm wide, with a slit-width of 0.03 mm (for minimum exposure), and had a blackening of from 0.5 to 1.0, according to measurement with a Hartmann microphotometer. The broadening of strongly affected zinc lines under just the same conditions was never less than 0.06 mm on the negatives. Reduced to tenth-meters, the

[1] On such spectrum photographs, where the sharpest definition is demanded, a change of 1 mm in the setting makes very marked changes on the plate, even with a total focal length of six meters.

zinc line at λ4810 for instance had in the arc a width of 0.07, against 0.19 in the spark (both with minimum exposure). The coincidence of the two lines at the point of their maximum intensity could nevertheless be readily demonstrated. If the spark was exposed twice as long, however, the unsymmetrical broadening is so great that the total width of the line amounted to from 0.53 to 0.71 t.-m., when it was difficult to find the maximum of intensity: the nucleus of the line runs toward the red, but the observer may still believe that he is setting on the maximum, and then readily finds an apparent shift of 0.008 t.-m., which rises to 0.02, and may become still larger with longer exposures, poor development, and defective settings due to deficiency of light. The cause of this pseudo-shift is to be sought in the fact that the nucleus of the line is no longer resolved. The focusing also has an effect not to be underestimated, for with a slightly inaccurate focus unsymmetrically broadened lines run out so as to be unrecognizable.

It is hard to decide whether this explanation of the highly contradictory statements of different spectroscopists who are photographing one and the same phenomenon is sufficient for all cases, but it is a fact that by carefully performing the spectrographic processes in the manner indicated we have been able to prove that all the alleged phenomena of shifts, described by Haschek for zinc, among other metals, *do not exist.*

Our experimental arrangements for producing the spark discharges between zinc electrodes followed strictly those conditions under which Haschek believed that he found "shifts." He states expressly in his "Spektralanalytischen Studien"[1] that the lines are more strongly shifted with a Ruhmkorff coil and hammer interrupter than with such a coil and a Wehnelt interrupter, or than with a transformer. We therefore also employed powerful induction coils with hammer interrupters, and indeed coils with a sparking distance of from 12 to 25 cm, having a corresponding battery of condensers, so that without doubt any real shift could not have escaped us.

Under these conditions, however, powerful effects of unsym-

[1] *Sitzungsberichte, Wien*, 110, IIa, 200, 1901.

metrical broadening appear for the zinc lines at λλ 4680, 4722, and 4810, and we then had before us one of the phenomena described as shifts by Exner and Haschek. Our heliogravure[1] shows two zinc spectra photographed precisely over one another, which clearly show the appearance of the "shift-phenomenon." In fact, on a superficial examination one would be disposed to speak here of a displacement of the lines, although a shift of the true maxima of intensity is actually not present. Similar erroneous "displacement phenomena" arise with various other experimental arrangements. This appearance is presented by overexposed photographs of zinc lines when one electrode of pure zinc is used, while the other is an alloy containing little zinc, which was regarded by Exner and Haschek as an effect of the partial pressure of the vapor. With defective definition of the spectra the comparison plates of zinc lines in the arc (narrow lines) and in the spark (unsymmetrically broadened) show a similar appearance. We remark, however, that the two spectra in our figure were obtained with one and the same zinc spark with a short and a long exposure (one-half minute as compared with five minutes), and that the spurious shift is only the photographic expression of the unsymmetrical broadening—just as the photography of a band of light with wedge-shaped shading always shows on prolonged exposure, even when the maxima of intensity are kept perfectly constant. Very short exposures bring out only the maxima of intensity, which coincide, while with long exposure the spark lines are more widened toward the red side than toward the side of shorter wave-lengths, and with somewhat longer development of the plate the maximum of intensity of the line blends with the unsymmetrical broadening. Having now discussed the conditions under which the phenomenon in question occurs, we can proceed to a description of the results of our own experiments, in which we carefully avoided all conditions which might be regarded as sources of error. With the accurate observance of the minimum exposures, with correct development of the plates, and with best definition of the spectra, it appeared (1) that at ordinary atmospheric pressure there exist no rela-

[1] Not reproduced here.—EDS.

tive shifts between the arc and spark spectra, as were said by Exner and Haschek to occur; (2) that there also exist no shifts in the spark spectrum which could be attributed to a reduced quantity of the element present in the vapor; that is, that a dependence on the partial pressure as assumed by Exner and Haschek cannot be proven.

In both cases there occur only the well-known variable, unsymmetrical broadenings, but the intensity-maxima of the lines coincide perfectly in our experiments.

We studied the same zinc lines for which Haschek observed shifts in the spark spectrum, and we first determined their wave-lengths as accurately as was practicable, using Rowland's standards as corrected by Kayser.[1] The lines were measured under the microscope, each line at least ten times each on different photographs, so that an accuracy of 0.002 t.-m. is reached in our wave-length.

Since the lines in the arc spectrum of zinc indicate the normal wave-lengths according to Haschek, and in his view are better adapted for determining the normal wave-length, at slight partial pressure (without fear of the alleged shift phenomena causing disturbance), we selected for producing the zinc arc small electrodes of brass wire, the composition of which was indicated by a chemical analysis to be 36.9 per cent. zinc and 63.1 per cent. copper.

The wave-lengths of the zinc lines in such a small arc between brass electrodes were determined with great care, as follows:

Third order	λ 3302.715
"	3303.068
"	3345.141
"	3345.698
"	3282.451
Second order	4680.327
"	4722.333
"	4810.719

In the same field of view with these were the copper lines of the third order at λλ 3247.671 and 3274.090 (Rowland), which

[1] "Normale aus dem Bogenspektrum des Eisens," *Ann. der Phys.*, **3**, 195, 1900.

always appear reversed in the arc (symmetrically widened), while the arc spectrum of the iron photographed on the plate for giving standard lines contained a trace of copper, and yielded a fine black *Cu* line which coincided perfectly with the reversal.[1]

Our heliogravure shows accurately a photograph of the arc spectrum of a zinc-copper alloy. It indicates how with increasing exposure all the lines of the arc spectrum remain quite sharp and broaden symmetrically. With increasing exposure pure zinc in the spark spectrum gives the lines λλ 4680, 4722, 4810 strongly broadened toward the red, but with accurate minimum exposure the brightest part of the line appears sufficiently sharp, in the strongest spark with condensers, for determining its wave-length accurately, and for establishing under the microscope the coincidence of the arc line, as may be seen on our plate. We similarly always found a perfect coincidence in the arc and spark for the zinc lines λλ 3282, 3302, and 3345.1; the spark lines of zinc at λλ 3345.1 and 3302.7 reverse very easily, and then coincide fully with the (unreversed) arc line. A broadening of this line toward the ultra-violet occurs with overexposure. The zinc lines at λλ 3345.698 and 3303.068, which can always be readily obtained as sharp and fine both in the arc and spark, are cited by Haschek himself as not subject to shift, because their tendency to remain sharp even for inaccurate exposure times prevents the illusions which may occur with defective definition for the unsymmetrically broadened lines of zinc at λλ4680, 4722, etc.

The illustration shows the beautifully accurate coincidence of the reversed arc lines of copper at λλ 3347 and 3274 with the unreversed spark lines. The zinc lines at λλ 4722 and 4810 are somewhat strongly exposed and developed for a strong degree of blackening. Hence the arc lines of the central spectrum are broadened pretty uniformly on both sides, while the spark lines show unsymmetrical broadening and the beginning of a spurious shift, which disappears with a minimum exposure and shorter development, making apparent the perfect coincidence of the

[1] In accordance with these experiments of ours, EXNER and HASCHEK also cite the two copper lines at λλ 3247 and 3274 as not subject to displacement in their *Wellenlängentabellen*, I, p. 21.

lines. The illustration further shows that the zinc lines at λλ3345 and 3302 are in no wise displaced toward the side of greater wave-length, as Haschek erroneously states. This can be seen much more distinctly on measuring the original negative under the microscope.

The suspicion that Haschek had imperfect definition in his spectra gains in probability by the fact that he failed to detect the finer structure of some of the zinc spark lines, which is quite remarkable. While he did not fail to notice the very strong unsymmetrical broadening toward the red of the zinc lines at λλ4680, 4722, and 4810, he did not observe that the zinc lines at λλ 3345.1 and 3302.7 exhibit a tendency to broaden slightly toward the side of the shorter wave-lengths, thus canceling the tendency toward an apparent "shift" toward the red. Nevertheless, Haschek finds these lines strongly shifted in the spark toward the red as compared with the arc, and we find, on the contrary, that with a correct short exposure there is no displacement whatever, but rather a coincidence.

After we had been unable to confirm the statements cited as to the relative shift between arc and spark lines, it remained to carry out further experiments on the effect of a partial pressure of the luminous zinc vapor on the "shift" of the lines. To this end we accurately investigated the spark spectrum of pure zinc and that of alloys of 1 per cent. zinc + 99 per cent. lead, and of 50 per cent. zinc + 50 per cent. lead, as well as alloys of 36.9 per cent. zinc + 63.1 per cent. copper. In accordance with the long since published, generally known, and never questioned experiences of all spectroscopists (and it holds good for all spectra, particularly in the case of unsymmetrically broadened lines), all the lines remain quite sharp even with the increased exposures for alloys containing *little* zinc; while for alloys containing *much* zinc they do, indeed, exhibit a strong tendency toward unsymmetrical broadening; and in so far the effect of a partial pressure on the width of the spectral lines unquestionably makes itself felt.

Hence with increasing exposures the effects of unsymmetrical broadening do not proceed in a parallel manner for alloys with a small and with a large proportion of zinc. If measurements

are therefore made on strongly exposed plates of such contrasted alloys, by setting on the middle of the ill-defined lines, apparent shifts will appear with increase of partial pressure, but they can be recognized instantly as pseudo-shifts on reverting to minimum exposures and on employing the best-defined spectra. An alloy of 1 per cent. of zinc to 99 per cent. of lead of course gives the separate zinc lines in the spark less bright than from an alloy containing more zinc. A preliminary trial with our strongest sparks (Ruhmkorff coil and jars) indicated that the low percentage alloy must receive an exposure of about 15 minutes as against 30 seconds for the 50 per cent. alloy, in order to obtain the lines at λλ 4680, 4722, and 4810 of approximately equal intensity on the plate. Accordingly, in this preliminary experiment the zinc lines were about thirty times brighter in the first case than in the second.

If we now employ an equivalent exposure time for the two cases, approximating the minimum exposures, which will give lines faint, but just measurable on the spectrogram, we find the wave-lengths of the zinc lines at λλ4680.327, 4722.333, and 4810.719 to be precisely the same in the spark spectrum with 1 per cent., 4 per cent., and 50 per cent. alloys and with pure zinc, and we were never able to observe even in the strongest spark from the jars the "shift" of Exner and Mache or of Haschek.

Haschek[1] states that alloys of 4 per cent. zinc give a wave-length of 4722.399; of 50 per cent. zinc, 4722.434; which would be a very considerable shift toward the red with increasing partial pressure. He found the line at λ 4680 too faint to be measurable in 4 per cent. alloy. This line, however, can be obtained sufficiently strong to be measurable with even a 1 per cent. alloy, if the exposure is correct (as is clearly shown in our illustration). It is evident that Haschek underexposed the low percentage alloy, and overexposed the other, and was deceived as a result of unsymmetrical broadening of the lines with poor definition of his spectra. So far as we can see, Haschek bases his theory of shifts solely on unsymmetrically broadened lines; for the sharp lines not even a pseudo-shift can be observed in the spark as compared with the arc spectrum.

[1] *Sitzungsberichte, Wien*, III, IIa, 238 and 240, 1902.

Our results accordingly are: (1) No displacements of meas urable magnitude occur in the spark spectrum of zinc as compared with the lines of the arc. (2) The quantity of the element present, or the partial pressure of its vapor, produces no displacement of the lines of the spark spectrum, and hence Haschek's system of quantitative spectrum analysis falls to the ground. *Per contra*, our observations establish the more certainly those principles (displacements of the lines due to motion in the line of sight according to Doppler's principle, etc.), which presuppose the constancy of the spectral lines, upon which doubt was cast by Haschek's conclusions.

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PRELIMINARY MEASUREMENT OF THE SHORT WAVE-LENGTHS DISCOVERED BY SCHUMANN.[1]

By THEODORE LYMAN.

THE work of Dr. Victor Schumann[2] on the extension of the spectrum beyond λ 1854 is too well known to need discussion. Dr. Schumann estimated the region of his extreme wave-lengths at 1000 Ångström units by an extension of the Helmholtz-Ketteler formula for fluorite, but up to the present time, as far as the author is aware, no direct measurements have been made.

It is now several years since the author first undertook the problem of making such measurements, but it is only very recently that his efforts have met with success. The apparatus used may be briefly described as follows: A concave diffraction grating of 97 cm radius, ruled on speculum metal with 15,028 lines to the inch, was mounted at one end of a brass frame, the other end of which carried the plate-holder and slits. The plate-holder itself was mounted in ways, and its position was controlled by a magnetic device of such a nature that seven exposures could be taken without removing the holder from the mounting. In the use of two slits the plan already described by the author[3] was followed. The illumination of the one slit allowed the spectrum under examination to fall upon the plate, while the illumination of the other caused a standard spectrum to fall upon the first. The shift of one spectrum with respect to the other is dependent on the distance between the slits, and was determined by comparison of the positions of known lines in each spectrum.

The angle of the grating was so adjusted that the part of the spectrum under investigation fell between the two slits, and the photographic plate, 4½ by 2½ cm, was therefore placed in this position. The centers of slits, spectrum, and grating surface lay

[1] Investigation carried on by grant from the Bache fund.

[2] *Smithsonian Contributions to Knowledge*, No. 1413.

[3] *Physical Review*, **16**, 261, 1903.

in one plane. The whole apparatus, held in adjustment by the frame, was slipped into a drawn-brass tube 110 cm long by 10.5 cm in diameter. The tube was closed permanently at one end, save for an outlet pipe, and was provided at the other with a flange, to fit which a circular brass plate was accurately ground. This plate was pierced by two windows covered, in the earlier experiments, by pieces of fluorite and corresponding in position to the slits of the spectroscope. A "Geryk" vacuum pump served to exhaust the apparatus. The pressures were read by a McLeod gauge.

In all the work the special photographic plates made according to the method described by Schumann[1] were used.

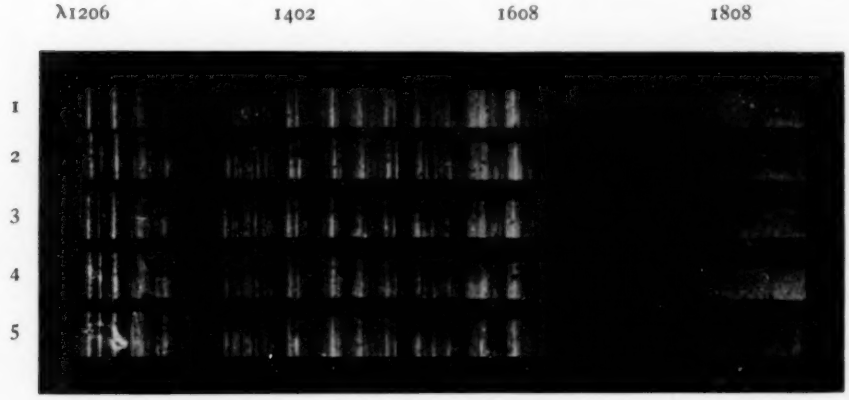
In the earlier work an "end-on" tube filled with hydrogen and closed by a fluorite window was pressed directly against the fluorite window of the apparatus. The pressure in the spectroscope was reduced to 0.08 mm of mercury; thus the light from the hydrogen passed through two plates of fluorite each 2 mm thick and through a column of air about two meters in length at a pressure of 0.08 mm of mercury. The line of shortest wavelength thus obtained had a value 1792 in Ångström units.

In order to eliminate the possible effect of the fluorite, an end-on tube without a window was sealed directly on to the brass plate, and the whole apparatus—spectroscope and discharge tube—was filled with pure, dry hydrogen. Thus the path of the light from the end-on tube to the photographic plate lay entirely in hydrogen. The discharge tube was excited by a transformer run from a 60 cycle alternating circuit and giving a potential difference of 3,000 volts in the secondary. A capacity of about 0.005 microfarads was placed in parallel with the tube.

With this arrangement, with an exposure of five minutes and with a pressure of 2 mm of mercury in the apparatus, a spectrum was obtained showing numerous sharp, strong lines, characterized by the following peculiarities: From the region of λ 1854 to that of λ 1700 the spectrum seems almost continuous, but contains some few faint lines. Near λ 1700 occurs an absorption band

[1] *Annalen der Physik*, 5, 349, 1901.

whose width seems to depend on the purity of the hydrogen in the apparatus. From λ 1650 the spectrum consists of numerous fine lines, 134 of which have been measured. The most refrangible of these yet observed has a wave-length of 1033. Owing to the dimensions of the plate, only a region of about 760 tenth-meters can be photographed at one time. Thus in the first experiments, where the line at the less refrangible end of the plate had the value λ 1935.2, the limit of short wave-lengths



LINES IN EXTREME ULTRA-VIOLET.

(The defects are on the original negative, and are due to the great difficulty of preparing the Schumann ultra-violet plates.)

was λ 1178. In order to study the region of still shorter wave-length, it was necessary to turn the grating.

The wave-lengths of the lines in the region between λ 1854 and λ 1178 have been carefully determined; but the values beyond this point are only approximate. The error in the region below λ 1178 probably does not exceed one unit. In the values given for the five lines above λ 1178 there may be an error of three units. The strongest line is given the intensity 10.

The plate which accompanies this article shows a twofold enlargement of the spectrum between wave-lengths 1200 and 1880. The spectra, numbered 1, 2, 3, 4, and 5, illustrate the effect which the purity of the hydrogen in the spectroscope seems to have upon the extent of the absorption band near

Wave-Length in Vacuum	Intensity	Wave-Length in Vacuum	Intensity	Wave-Length in Vacuum	Intensity
1033	1	1387.6	1	1541.4	5
1046	1	1393.8	5	1544.1	9
1105	3	1396.0	5	1546.7	9
1118	1	1397.6	1	1550.0	6
1145	1	1402.4	7	1552.9	6
1162	5	1410.1	1	1565.1	6
1178.1	1	1412.5	1	1567.0	6
1180.4	4	1427.3	3	1568.9	6
1182.7	1	1429.6	3	1571.3	6
1185.0	1	1432.5	5	1573.7	1
1188.1	4	1435.9	6	1577.1	6
1189.8	4	1437.5	3	1579.0	1
1205.1	5	1440.4	7	1581.0	6
1206.7	5	1443.2	5	1583.8	2
1215.6	7	1454.3	4	1585.5	2
1228.3	5	1455.9	1	1587.4	1
1229.9	7	1457.6	3	1588.8	6
1232.0	3	1459.7	3	1591.2	5
1246.2	1	1462.1	4	1593.2	3
1247.6	1	1463.5	4	1595.8	7
1253.8	2	1466.6	4	1599.1	1
1257.2	2	1468.1	4	1601.6	10
1262.0	3	1470.5	1	1604.1	4
1276.7	2	1472.2	1	1604.9	4
1279.3	3	1479.1	2	1607.8	10
1283.2	3	1481.2	2	1610.0	4
1284.6	2	1483.2	2	1611.5	1
1331.6	1	1486.0	8	1613.0	9
1334.1	4	1488.7	7	1614.7	1
1336.0	4	1491.3	3	1616.4	2
1338.8	2	1494.9	10	1620.6	4
1342.5	6	1499.2	2	1623.0	5
1345.2	5	1504.2	2	1625.5	1
1347.2	5	1510.8	4	1628.0	4
1352.5	2	1513.0	4	1633.5	6
1353.6	3	1514.5	4	1636.0	3
1355.5	2	1517.0	5	1640.0	3
1357.5	5	1518.3	5	1641.2	2
1363.5	8	1519.1	1	1642.4	1
1365.6	3	1522.6	6	1644.1	3
1367.8	3	1530.2	4	1792.5	1
1371.1	5	1532.4	4	1810.8	1
1377.1	3	1534.3	2	1877.7	1
1380.4	3	1536.9	4		
1385.7	1	1538.9	1		

λ 1700. No. 1 was obtained after the apparatus had been filled but once with gas and then pumped to a pressure of 2 mm. No. 5 shows the result after the spectroscope had been flushed five times with hydrogen.

Reference has already been made to the paper in which the method of using the comparison spectrum is explained. The

above measurements rest on the aluminium lines λλ 1854, 1862.2, 1935.2 . . . . as determined by Runge, and upon lines in the comparison cadmium spectrum. The wave-lengths of these lines are those given by Exner and Haschek. The correction to vacuum was obtained from the work of Kayser and Runge.

The author makes no claim that all of these lines belong to the spectrum of hydrogen. He can only state that an end-on vacuum tube, connected directly to a large brass cylinder filled with pure, dry hydrogen, produces such a spectrum. Under the circumstances, any speculation as to the possible series relations existing between these short wave-lengths would be premature.

The author is at present engaged in an attempt to determine the sources of the lines already observed, by a study of the emission and absorption spectra of other gases in this region.

The present paper is entirely of a preliminary character. It is the author's purpose to publish a more complete description of apparatus and results at some future time.

The chief result of this investigation is the measurement of the short wave-lengths, whose existence was first discovered by Schumann. It is, however, of interest to note that the considerable reflective power of speculum metal for these short waves has incidentally been demonstrated.

JEFFERSON PHYSICAL LABORATORY,
Harvard University, Cambridge, Mass.
March 28, 1904.

INVESTIGATIONS ON THE SPECTRUM AND ORBIT OF δ *ORIONIS*.[1]

By J. HARTMANN.

ONE of the first results obtained by M. Deslandres with the new spectrograph attached to the 62 cm refractor of the observatory at Meudon was the discovery of the "oscillation" of δ *Orionis*. I use the term "oscillation" in place of the ponderous expression "variability of velocity in the line of sight;" but the idea of oscillation is still somewhat broader, as it includes every sort of periodic variation in the spectrum, without saying anything as to its explanation.

After the publication[2] of the discovery mentioned, which was communicated to the Paris Academy on February 12, 1900, Director Vogel instructed the observers in the field of stellar spectroscopy at Potsdam to undertake to confirm the interesting phenomenon, and the observations made with the four different spectrographs then in use here proved beyond a doubt that δ *Orionis* belongs to the number of oscillating stars. A confirmation of the discovery was also given by three observations by Wright with the Mills spectrograph of the Lick Observatory.

Deslandres derived from his eleven observations a period of 1.92 days, and concluded that the orbit was very eccentric. The observations which I made at that time with the large Spectrograph III (with three prisms) attached to the 80 cm refractor could not, however, be brought into accord with that length of period; and since the measures showed that the star could be more advantageously observed with low dispersion, on account of the extreme diffuseness of its lines, I included it in the program of Spectrograph I (with only one prism). With this instrument I made in the winter months of 1901–2 and 1902–3 an extensive series of observations, which will now be discussed.

[1] Translated from advance proofs, sent by the author, with additions, of a paper to appear in the *Sitzungsberichte der Kgl. Akademie der Wissenschaften zu Berlin*.

[2] H. DESLANDRES, "Variations rapides de la vitesse radiale de l'étoile δ *Orion*," *Comptes Rendus*, 130, 379, 1900.

It may be remarked here that my observations have not confirmed the period deduced by Deslandres, the true period exceeding three times the value given by him. The eccentricity is also only slight. It is true, as I have convinced myself, that Deslandres' observations happen to be pretty well represented by a period of 1.92 days, with the exception of his first and last measures, which were

1899, December 8.4, $V = +95$ km; 1900, January 25.3, $V = -50$ km.

If we add twenty-five times the period to the epoch of the first observation, $25 \times 1^d92 = 48^d0$, we get 1900, January 25.4, $V = +95$ km, which contradicts the last observation. But the period I have derived well represents all of the observations of Deslandres.

Table I contains the list of my observations, the Roman numerals in the first column being used to designate the spectrograph used. Plates IV 431 and IV 435 were made with Spectrograph IV attached to the 33 cm refractor by Dr. Ludendorff, who also assisted me with the plates taken with Spectrograph I attached to the 80 cm refractor. In the column headed "Julian Day," the first three figures 241 are always omitted, as also later in the text, and the times are always expressed in Greenwich mean time. V is the observed velocity in the line of sight relative to the Sun, and ϵ is the mean error of this number, computed from the internal agreement of the results derived from the different lines. L is the number of lines used in computing the velocity. The last two columns will be explained later.

δ Orionis belongs to the type of *Orion* stars (I*b*), whose spectrum shows, besides the hydrogen lines, chiefly the lines of helium, all of which in this case are exceedingly diffuse and dim, so that their measurement is very difficult and uncertain. On account of the slight intensity of the lines, all defects of the film are very disturbing, and, in consequence of irregular distribution of the silver grains, the lines often appear crooked and unsymmetrical, sometimes indeed double. I have convinced myself by a special investigation that the indications of duplicity and unsymmetrical broadening cannot be caused by lines belonging

TABLE I.

Plate Number	Greenwich M. T.	Julian Day	V	ϵ	L	C	$V-C$
			km	km		km	km
III 41	1900, Feb. 25 6^h48^m	$5076^d.28$	+ 84.0	± 6.0	1	+ 83.6	+ 0.4
III 43	Mar. 1 6 25	5080.27	− 45.4	17.0	2	− 66.4	+21.0
III 49	7 6 8	5086.26	− 49.4	5.0	2	− 58.5	+ 9.1
IV 431	1901, Jan. 5 8 7	5390.34	− 24.5	....	1	− 44.7	+20.2
IV 435	9 8 2	5394.33	− 30.9	....	1	− 28.6	− 2.3
I 153	Nov. 23 10 6	5712.42	+ 63.5	2.9	6	+ 63.3	+ 0.2
I 189	1902, Jan. 13 7 19	5763.30	− 3.3	5.7	8	− 17.4	+14.1
I 191	13 9 35	5763.40	+ 6.1	6.9	9	− 7.8	+13.9
I 196	14 8 32	5764.36	+ 92.2	8.4	10	+103.2	−11.0
I 200	14 10 35	5764.44	+110.5	4.8	8	+110.0	+ 0.5
I 204	16 8 35	5766.36	+ 27.0	3.1	6	+ 23.5	+ 3.5
I 215	Feb. 4 10 11	5785.42	− 65.0	9.1	6	− 65.1	+ 0.1
I 221	10 8 50	5791.37	− 45.1	6.6	6	− 58.0	+12.9
I 224	11 6 9	5792.26	+ 17.8	6.1	6	+ 13.6	+ 4.2
I 226	12 5 46	5793.24	+124.9	9.5	2	+120.5	+ 4.4
I 227	13 5 22	5794.22	+107.1	6.3	6	+104.5	+ 2.6
I 231	14 5 26	5795.23	+ 3.9	6.5	6	+ 3.0	+ 0.9
I 232	15 4 42	5796.20	− 63.0	3.0	6	− 61.1	− 1.9
I 234	16 5 1	5797.21	− 52.3	3.0	7	− 52.9	+ 0.6
I 245	Mar. 5 6 20	5814.26	− 59.6	6.1	8	− 59.8	+ 0.2
I 247	6 5 26	5815.23	+ 27.3	3.3	7	+ 18.0	+ 8.6
I 253	11 7 20	5820.31	− 43.5	3.3	7	− 42.8	− 0.7
I 254	12 5 38	5821.23	+ 45.4	6.2	6	+ 50.6	− 5.2
I 256	13 5 35	5822.23	+128.4	7.0	7	+133.4	− 5.0
I 262	14 5 43	5823.24	+ 68.7	5.5	8	+ 69.8	− 1.1
I 266	April 2 6 13	5842.26	− 79.5	6.6	7	− 66.2	−13.3
I 268	2 7 22	5842.31	− 60.0	5.4	7	− 67.1	+ 7.1
I 284	9 7 6	5849.30	− 30.0	4.7	3	− 15.5	−14.5
I 288	10 6 46	5850.28	+ 81.2	3.8	7	+ 96.4	−15.2
I 475	Dec. 11 9 14	6095.38	− 49.3	4.1	7	− 48.4	− 0.9
I 481	12 8 53	6096.37	+ 47.2	0.8	6	+ 48.0	− 0.8
I 485	13 8 49	6097.37	+128.7	8.9	6	+133.2	− 4.5
I 491	14 11 1	6098.46	+ 56.1	4.9	6	+ 63.5	− 7.4
I 494	1903, Jan. 9 8 7	6124.34	− 32.7	7.7	8	− 26.5	− 6.2
I 495	12 9 23	6127.39	+ 38.2	7.1	8	+ 35.8	+ 2.4
I 501	13 8 12	6128.34	− 46.4	6.2	7	− 45.2	− 1.2
I 505	14 7 40	6129.32	− 69.3	3.5	5	− 66.4	− 2.9
I 509	17 8 32	6132.36	+127.1	7.5	9	+111.0	+16.1
I 523	Feb. 7 8 51	6153.37	0.0	2.3	7	+ 9.2	− 9.2
I 527	Mar. 7 5 28	6181.23	− 54.9	6.0	9	− 55.8	+ 0.9
I 535	12 5 51	6186.24	− 61.2	7.3	9	− 66.7	+ 5.5
I 541	15 6 9	6189.26	+135.4	5.2	6	+132.7	+ 2.7

to a second component of the stellar system; but I do not hold it to be impossible that the form of the lines is subject to small real changes, perhaps in consequence of violent motions in the gaseous envelope of the star.

Although we must, accordingly, regard δ *Orionis* as a binary system having one of its components "dark," in the customary

phrase, I would nevertheless point out that by "dark" we here must understand only a relatively small difference of brightness. A difference of only about one magnitude would be sufficient to bring the spectrum of the fainter component to almost complete disappearance, and a difference of two magnitudes would make it impossible for even a trace of the fainter spectrum to be visible on the plate. The slight difference of magnitude necessary for the extinction of the fainter spectrum explains the fact that among the numerous spectroscopic binaries so far discovered there are very few which show the lines of the second component in the spectrum.

The great diffuseness of the lines of this spectrum gives large play to personality effects of the observer, and in order to reach trustworthy results it is therefore necessary that everything subjective should be, as far as possible, eliminated from the observations. To this end I have observed the following rules in these measurements, which were all made by myself: In the first place every plate was measured wholly independently in the two positions of the plate, violet toward the right and violet toward the left. While this procedure is to be highly recommended even for spectra with sharp lines, as I have elsewhere shown,[1] it is wholly essential for diffuse lines, since here the psycho-physical errors in the estimates of the centers of the lines reach extremely high values. Secondly, every prepossession of the observer was most strictly avoided during the measurements, the reduction of the observations and the drawing of the velocity curve not being undertaken until all the measures had been entirely concluded. Finally, in order to obtain as accurate velocities as possible, and fully to dispose of the data of the plate employed in this discussion, I adopted the rule of measuring *all* of the lines that could be recognized on each plate. Thus I have been able to measure twenty different lines in all, while the measures of all earlier observers using high dispersion were limited to the $H\gamma$ line. For the determination of the velocity itself, however, only those lines could be used which permitted a fairly safe measurement on the majority of the plates and whose wave-lengths were

[1] *Astronomische Nachrichten*, 155, 97, 1901.

known with sufficient accuracy. The following eleven lines were of this kind:

TABLE II.

Name	Element	λ
$H\zeta$	*H*	3889.20
He	*H*	3970.23
	He	4026.34
	Si	4089.00
$H\delta$	*H*	4101.89
$H\gamma$	*H*	4340.64
	He	4388.10
	He	4471.65
	Mg	4481.38
$H\beta$	*H*	4861.50
	He	4922.10

The wave-lengths of the nine remaining lines, which are collected in Table III, I have calculated from measurements in the star spectrum itself. On account of the exceeding difficulty of their measurement, they are indeed rather unreliable, as is shown by the mean error given in the third column, but they are nevertheless sufficient to render possible an accurate identification in connection later with other stars of the same type.

TABLE III.

λ	No. of Plates	Mean Error	Remarks
3933.68	7	(±0.34)	*Ca;* always exceedingly weak and narrow.
4069.49	3	±0.16	
4097.49	5	0.14	*Si*
4116.28	11	0.07	*Si*
4144.94	2	0.28	
4200.42	2	0.20	$H\delta'$ according to Pickering's nomenclature.
4541.78	2	0.41	$H\gamma'$ according to Pickering's nomenclature.
4649.68	16	0.14	Probably a group; 4 tenth-meters wide.
4686.20	10	0.12	

Among the lines in Table III the calcium line at λ 3934 exhibits a very peculiar behavior. It is distinguished from all the other lines of this spectrum, first by the fact that it always appears extraordinarily weak, but almost perfectly sharp; and it therefore attracted my attention that in computing the wave-lengths collected in Table III for this particular line, the agree-

ment between the results from the different plates was decidedly less than for the other, much less sharp lines. Closer study on this point now led me to the quite surprising result *that the calcium line at λ 3934 does not share in the periodic displacements of the lines caused by the orbital motion of the star.*

As appears from Table III, I had in the first measurement of the negatives measured this line on seven plates, on which it was particularly well recognizable. In order fully to assure the peculiar result found, I then subjected the whole set of plates to another examination, when in all twelve were found on which the line could be measured with accuracy. The results of this second measurement, which was of course again carried out with the strictest avoidance of all prepossession, are contained in the column headed II in Table IV, the original measurements being given in column I. In this table I have arranged the plates in order of the values of V, the true velocity of the star relative to the Sun, computed from the orbit. The velocities deduced from the calcium line alone are designated by C' (relative to the Earth), and C (relative to the Sun).

TABLE IV.

Plate Number	V	C' from λ 3934			Reduction to Sun	C	Diff.
		I	II	Mean			
	km	km	km	km	km	km	km
I 247	+ 18.0	+44	+39	+42	−27	+15	− 1
I 254	+ 50.6	....	+44	+44	−27	+17	+ 1
I 153	+ 63.3	+11	+11	+11	+ 9	+20	+ 4
I 485	+133.2	+24	+19	+22	0	+22	+ 6
I 491	+ 63.5	+ 3	+ 7	+ 5	− 1	+ 4	−12
I 495	+ 35.8	....	+38	+38	−14	+24	+ 8
I 204	+ 23.5	+35	+25	+30	−16	+14	− 2
I 231	+ 3.0	....	+40	+40	−25	+15	− 1
I 232	− 61.1	+25	+32	+28	−25	+ 3	−13
I 266	− 66.2	+46	+49	+48	−26	+22	+ 6
I 215	− 65.1	....	+43	+43	−23	+20	+ 4
I 221	− 58.0	....	+42	+42	−24	+18	+ 2

Mean +16 km

As appears from the differences from the mean, given in the last column, the values of C are wholly independent of V, and hence of the orbital position of the star; they are also in as good

agreement as could be expected in view of the difficulty of the measurements.

The fact being thus fully established that a single line of the spectrum does not participate in the oscillatory motion of the other lines, the question arises as to how it can be explained. The character of the absorption corresponding to the line makes it highly improbable that it should have originated in the Earth's atmosphere. In that case, moreover, the line in question would have to appear in every stellar spectrum, and the velocities C' computed from its position would come into worse agreement on applying the correction for reduction to the Sun. But the case is quite the opposite—the value of C does not become constant until after applying the reduction to the Sun, and thus the cosmical origin of the line is proven.

The most natural assumption, that the observed line belongs to the second component of the binary system, encounters two difficulties. Since the values of C in Table IV indicate no dependence upon V, we should have to assume for the fainter component a mass *at least* ten times as great as that of the brighter star. While this is itself very improbable, it is still more surprising that not a single other line should be revealed of the spectrum of the second body. The occurrence of such an isolated line would be explained by none of the spectral types hitherto known, and it points rather with a pretty fair degree of certainty to the presence of an absorbing layer of gas not in immediate connection with the star.

We are thus led to the assumption that at some point in space in the line of sight between the Sun and δ *Orionis* there is a cloud which produces that absorption, and which recedes with a velocity of 16km, in case we admit the further assumption, very probable from the nature of the observed line, that the cloud consists of calcium vapor. This reasoning finds a distinct support in a quite similar phenomenon exhibited by the spectrum of *Nova Persei* in 1901. While the lines of hydrogen and other elements in that spectrum led us, by their enormous broadening and displacement and the continuous changing of their form, to conclude that stormy processes were going on within the gaseous envelope of

the star, the two calcium lines at λ 3934 and λ 3969, as well as the D lines, were observed as perfectly sharp absorption lines, which yielded the constant velocity of + 7 km during the whole duration of the phenomenon. I then expressed the opinion that these sharp lines probably did not have their origin in the *Nova* itself, but in a nebulous mass lying in the line of sight — a view which only gained in probability on the later discovery of the nebula in the neighborhood of the *Nova*. In the case of *δ Orionis* also it is not unlikely that the cloud stands in some relation to the extensive nebulous masses shown by Barnard[1] to be present in the neighborhood. The second calcium line at λ 3969 is concealed in the spectrum of *δ Orionis* by the broad hydrogen line *He*, and therefore cannot be observed.

I would also call attention at this point to a further peculiar phenomenon. If we compute the component of the solar motion $V\odot$ according to Campbell's[2] provisional elements of the apical motion, we obtain:

for *δ Orionis* - $V\odot = +18.1$ km
for *Nova Persei* $V\odot = +8.7$ km

These figures agree within the errors of observation with the observed velocity of the calcium clouds, which therefore in these two cases are almost completely at rest relatively to the 280 stars employed by Campbell.

The point in the line of sight at which the nebulous mass lies cannot be ascertained. In order to determine its lateral extension the spectra of neighboring stars, particularly those with variable or distinctly different velocity, should be examined for the occurrence of the calcium line. It is present in the spectrum of *ε* and *ζ Orionis*, but inasmuch as the velocities of these stars differ only slightly from the motion of the cloud given above, we cannot distinguish whether it belongs to the spectrum of the star or of the cloud.

In a similar manner I have also tested the behavior of the other lines of Table III, but I am unable to detect anything similar in the case of any one of them.

[1] "Diffused Nebulosities in the Heavens," ASTROPHYSICAL JOURNAL, 17, 77, 1903.

[2] "A Preliminary Determination of the Motion of the Solar System," *ibid.*, 13, 80, 1901.

After these remarks on the spectrum of δ *Orionis*, I now proceed to the determination of the orbit.

The observations on seven successive days in February 1902 first proved beyond a doubt that the period was not 1.92 days, but from five to six days. Successive plates taken on the same evenings (1902, January 13, January 14, and April 2) showed that the period could not be still shorter, as has been suspected by Deslandres. The inclusion of successively more widely separated observations then gave in the customary manner the provisional value of the period $5^d.7333$. This value is accurate to $0^d.001$, and is therefore sufficient for reducing all observations of each winter to one revolution, and thus to make it possible to draw the velocity curve.

At first I drew this curve separately for the different years, since it looked as if the orbit might be markedly variable with the time. Four observations by Vogel and Scheiner in the years 1888 to 1891 did not permit of recognition of any variation in the star's velocity. These are given on p. 100 of Part I of Vol. VII of the Publications of the Astrophysical Observatory at Potsdam, and are as follows:

1888, December 10.37	− 2.7 km
1889, January 5.34	− 0.1
1891, February 26.26	+ 2.4
February 27.26	+ 3.7

Then followed in 1899 and 1900 the observations of Deslandres, of Wright, and of the writer, which yielded velocities from − 69 to + 95 km, and finally my measures in 1902 and 1903 indicated a range from − 79.5 to + 135.4 km. The amplitude of the variation accordingly appeared to increase greatly, which could have been readily explained by the assumption of a change in the inclination of the plane of the orbit to the line of sight.

On this point the Potsdam plates from 1888 to 1891 were now decisive. On computing backward with the given period and the present range of velocity, it appeared that the first two early observations happened to have been made at times when the velocity of the star was actually very small, so that the variability might easily escape the observers. *Per contra*, at the

third observation the velocity must have been about — 50 km, and at the fourth, about + 50 km, whence the variation should have been detected with certainty on those plates, in case the amplitude of variation had not actually changed in the meantime. Professor Vogel was therefore kind enough to remeasure the four plates, and found for the first and second plates a confirmation of the former results, but he experienced a decided change in his impression as to the settings (*Auffassung*) for the third and fourth plates. On those early plates the artificial hydrogen line fell across the star spectrum, so that the observation was rendered exceedingly difficult, particularly for stars of the first type, in which only the diffuse *Hγ* line was measured. Doubtless as the result of the good agreement of the first two plates, the observers measured the third and fourth plates with an incorrect *Auffassung* of the line. The remeasurement led to the following velocities:

− 8.8 km
+ 3.7
− 55.0
+ 13.3

These agree so well with the present motion that we may abandon the assumption of a change in the orbit. The observations of 1899 and 1900 further do not of themselves force us to this assumption. The dates of the observations fall so that the maximum positive velocity never happened to be observed, whence the amplitude would appear to be smaller. As I shall show farther on, these observations can also be accurately represented by the present orbit. Finally, the two velocity curves drawn from my observations in the winters of 1901–2 and 1902–3 were perfectly similar and could be accurately superposed. For these reasons I gave up my original plan of computing an independent orbit for each season's observations, and my orbit is based upon my whole series of observations made with Spectrograph I in the winters of 1901–2 and 1902–3. I decided not to employ the older measures for the orbit, first, because all these determinations made with higher dispersion are decidedly less accurate, and second, because a slight alteration in the assumed

period of revolution would have too strongly affected these remote observations. Therefore I have employed the early Potsdam series only for deriving the definitive period.

I adopted the following method for transferring with entire certainty the observations of the winter of 1902–3 to the preceding year. After velocity-curves had been drawn separately for the two years, as already stated, the times were read off on the two curves, both on the ascending and descending branches, at which the velocities were $-50, -40, \cdots\cdots +100, +110$ km. In this way were obtained thirty-four determinations of the difference in time by which the second curve (from observations of 1902–3) must be displaced in order to superpose it upon those of 1901–2. The mean of the thirty-four differences was $332^d.53$; since this number is equal to fifty-eight revolutions, the result follows: $P = 5^d.7333$, which happens to agree precisely with the value given above.

After all of the thirty-seven plates made with Spectrograph I had been in this way transferred to the single revolution of 1902, February 10–16, the elements of the orbit were determined by the method of Lehmann-Filhés[1] with the following result:

ELEMENTS.

Velocity of the center of gravity	$V_0 = +23.1$ km
Epoch of periastron	$T = 5793.35 = 1902$, Feb. 12.35
Epoch for $V = 0$	$t_0 = 5792.13 = 1902$, Feb. 11.13
Longitude of the perihelion (from ☊)	$\omega = 33^\circ\ 18'.9$
Longitude of the farthest point of the orbit	$u_1 = 95^\circ\ 32'.9$
Longitude of the nearest point of the orbit	$u_2 = 264^\circ\ 27'.1$
Eccentricity	$e = 0.10334$
Projection of semi-major axis on the line of sight	$a \sin i = 7906600$ km
Ratio of masses	$\frac{m_2^3 \sin^3 i}{(m_1 + m_2)^2} = 0.601\ \odot$

Since we do not know the inclination of the orbit to the tangential plane passing through the center of gravity of the orbit

[1] *Astronomische Nachrichten*, 136, 17, 1894.

perpendicular to the line of sight, the value of the semi-axis a cannot be computed, but we can give the distances which the visible star reaches behind and in front of this plane, to which the longitudes designated above with u_1 and u_2 correspond. It results that the star moves as far as 8069400 km behind this plane and out to 7498500 km in front of the plane. If we make the following assumptions as to the inclination, we get these results:

$i = 45°$	$a = 11182000$ km
$60°$	9129800
$75°$	8185600
$90°$	7906600

We see from this that the orbit has something like one-sixth the diameter of the orbit of *Mercury*, in case we do not assume i to be very small. If the masses of the two components of the binary system are nearly equal—a point which I shall presently discuss more fully—the separation of the stars would accordingly be about one-third of the distance of *Mercury* from the Sun.

Since nothing is known as to the motion of the second component, we can compute for the mass of the system only the relation given above,

$$\frac{m_2^{\frac{1}{3}} \sin^3 i}{(m_1 + m_2)^2} = 0.601 \odot ,$$

in which m_1 is the mass of the visible, and m_2 that of the invisible, star. Here also we can reach at least approximate estimates of the true relations by reasonable assumptions.

All spectroscopic binaries for which it has been possible to observe the second component consist of two stars of nearly equal mass, and it can be shown also in the case before us that a dark star cannot be essentially smaller than the visible one. If we first calculate the very improbable case $m_2 = 5m_1$, that is, where the dark star is five times as massive as the bright one, we get

$$\begin{aligned} m_2 \sin^3 i &= 0.865 \odot \\ m_1 \sin^3 i &= 0.173 \odot \\ \hline (m_1 + m_2) \sin^3 i &= 1.038 \odot \end{aligned} .$$

Therefore in this case the total mass of the system would certainly be larger than that of the Sun. Similarly if we make

the calculations for the assumptions $m_1 = m_2$, $m_1 = 5m_2$, and $m_1 = 10m_2$, we shall obtain the values of the masses given in Table V.

TABLE V.

	$m_1 \sin^3 i$	$m_2 \sin^3 i$	$(m_1 + m_2) \sin^3 i$
$m_1 = 0.2m_2$	0.173 ⊙	0.865 ⊙	1.038 ⊙
$m_1 = m_2$	2.404	2.404	4.808
$m_1 = 5m_2$	108.2	21.6	129.8
$m_1 = 10m_2$	727.2	72.7	799.9

As the table shows, if we assume m_1 to be notably larger than m_2, we reach enormous masses, quite aside from the factor $\sin^3 i$, and therefore it may be regarded as most probable that the two masses are nearly equal for the case of δ *Orionis*. If we now repeat the computations for the previously assumed values of i, on the assumption that $m_1 = m_2$, we get

$i = 45°$	$m_1 + m_2 = 13.6$ ⊙
60	7.4
75	5.3
90	4.8

We see from these considerations that the total mass of the system is certainly greater than the solar mass, and probably of the order of from five to ten times the solar mass.

In order to facilitate the comparison with the calculated orbit of the observations at present before us, as well as possible later ones, I have computed the ephemeris given in Table VI from the above elements. The argument τ is reckoned from that point of time at which V passes through zero when increasing, and which is obtained from $t_0 + nP$, where n is a whole number.

I have now employed this ephemeris in the following manner, in order to employ the early Potsdam observations in deriving the definitive period: If the early observation gave the velocity V at the time t, the value of τ corresponding to T is sought in Table VI, and the time $t_0 + \tau$ then corresponds to the same point of the orbit as t, so that $t_0 + \tau - t$ is always a whole number of periods. The approximate period is sufficient for previously determining whether τ falls on the ascending or descending part of the curve.

TABLE VI.

τ	0d	1d	2d	3d	4d	5d
	km	km	km	km	km	km
0d.00	+ 0.0	+112.3	+111.7	+12.6	−58.7	−56.8
01	1.0	113.1	111.0	11.6	59.0	56.3
02	2.0	113.9	110.2	10.6	59.4	55.8
03	3.0	114.6	109.4	9.7	59.8	55.4
04	4.0	115.4	108.6	8.7	60.2	54.9
05	+ 5.0	+116.1	+107.8	+ 7.8	−60.5	−54.4
06	6.0	116.9	107.0	6.8	60.8	53.9
07	7.0	117.6	106.2	5.9	61.1	53.4
08	8.1	118.3	105.4	4.9	61.4	52.9
09	9.2	119.0	104.5	4.0	61.7	52.4
0.10	+10.3	+119.8	+103.7	+ 3.0	−62.0	−51.8
11	11.4	120.5	102.8	2.1	62.3	51.3
12	12.5	121.2	102.0	1.1	62.6	50.7
13	13.6	121.8	101.1	+ 0.2	62.9	50.2
14	14.7	122.4	100.2	− 0.8	63.1	49.6
15	+15.8	+123.1	+ 99.3	− 1.7	−63.4	−49.0
16	16.9	123.7	98.4	2.7	63.6	48.4
17	18.0	124.3	97.5	3.6	63.9	47.8
18	19.2	124.8	96.5	4.5	64.2	47.2
19	20.3	125.4	95.6	5.4	64.4	46.6
0.20	+21.5	+125.9	+ 94.6	− 6.4	−64.7	−46.0
21	22.6	126.4	93.7	7.3	64.9	45.4
22	23.8	127.0	92.7	8.2	65.1	44.7
23	25.0	127.5	91.7	9.2	65.4	44.1
24	26.2	128.0	90.7	10.1	65.6	43.4
25	+27.3	+128.4	+ 89.8	−11.0	−65.8	−42.8
26	28.5	128.9	88.8	11.9	66.0	42.1
27	29.7	129.3	87.8	12.8	66.2	41.4
28	30.9	129.7	86.8	13.7	66.4	40.7
29	32.1	130.1	85.8	14.6	66.6	40.0
0.30	+33.4	+130.4	+ 84.9	−15.4	−66.7	−39.3
31	34.6	130.8	83.9	16.2	66.9	38.6
32	35.8	131.1	82.9	17.0	67.1	37.8
33	37.0	131.4	81.9	17.8	67.3	37.1
34	38.2	131.6	80.9	18.6	67.4	36.3
35	+39.5	+131.9	+ 80.0	−19.4	−67.5	−35.6
36	40.7	132.1	79.0	20.2	67.6	34.8
37	41.9	132.4	78.0	21.0	67.7	34.0
38	43.1	132.6	77.0	21.8	67.7	33.2
39	44.3	132.7	76.0	22.6	67.8	32.4
0.40	+45.6	+132.9	+ 74.9	−23.4	−67.9	−31.6
41	46.8	133.0	73.9	24.2	67.9	30.8
42	48.0	133.2	72.9	24.9	68.0	29.9
43	49.3	133.3	71.9	25.7	68.0	29.1
44	50.6	133.4	70.8	26.4	68.0	28.2
45	+51.8	+133.5	+ 69.8	−27.2	−68.0	−27.3
46	53.1	133.6	68.7	27.9	68.0	26.5
47	54.4	133.7	67.7	28.6	68.0	25.6
48	55.7	133.7	66.7	29.4	68.0	24.7
49	57.0	133.7	65.6	30.2	68.0	23.8

TABLE VI.—*Continued.*

τ	0^d	1^d	2^d	3^d	4^d	5^d
	km	km	km	km	km	km
$0^d.50$	+ 58.2	+133.7	+64.6	−30.9	−68.0	−22.9
51	59.5	133.7	63.5	31.6	68.0	22.0
52	60.8	133.7	62.5	32.3	68.0	21.1
53	62.0	133.6	61.5	33.0	68.0	20.2
54	63.3	133.5	60.4	33.7	67.9	19.3
55	+ 64.5	+133.4	+59.4	−34.3	−67.9	−18.3
56	65.8	133.3	58.3	35.0	67.8	17.4
57	67.0	133.1	57.3	35.7	67 8	16.4
58	68.2	132.9	56.2	36.4	67.8	15.5
59	69.4	132.7	55.2	37.0	67.7	14.5
0.60	+ 70.5	+132.5	+54.1	−37.7	−67.7	−13.5
61	71.7	132.3	53.1	38.3	67.6	12.5
62	72.9	132.0	52.0	39.0	67.5	11.5
63	74.1	131.7	50.9	39.7	67.4	10.5
64	75.3	131.4	49.8	40.3	67.3	9.5
65	+ 76.4	+131.1	+48.8	−41.0	−67.2	− 8.5
66	77.6	130.8	47.7	41.6	67.0	7.5
67	78.8	130.4	46.6	42.2	66.9	6.5
68	80.0	130.0	45.5	42.8	66.8	5.5
69	81.2	129.7	44.4	43.4	66.6	4.5
0.70	+ 82.4	+129.3	+43.4	−44.0	−66.4	− 3.5
71	83.6	129.0	42.3	44.6	66.2	2.5
72	84.8	128.6	41.2	45.2	66.0	1.4
73	86.0	128.1	40.1	45.8	65.8	− 0.4
74	87.2	127.7	39.0	46.4	65.6	+ 0.7
75	+ 88.3	+127.2	+38.0	−46.9	−65.4	+ 1.7
76	89.5	126.8	36.9	47.5	65.1	2.8
77	90.7	126.3	35.8	48.1	64.9	3.9
78	91.8	125.8	34.8	48.7	64.6	4.9
79	93.0	125.3	33.7	49.2	64.4	6.0
0.80	+ 94.1	+124.8	+32.7	−49.7	−64.1	+ 7.1
81	95.3	124.3	31.6	50.2	63.9	8.2
82	96.4	123.8	30.6	50.7	63.6	9.3
83	97.4	123.3	29.6	51.2	63.3	10.4
84	98.4	122.7	28.6	51.7	63.0	11.5
85	+ 99.4	+122.2	+27.5	−52.2	−62.7	+12.6
86	100.4	121.6	26.5	52.6	62.3	13.7
87	101.4	121.0	25.5	53.1	62.0	14.8
88	102.3	120.4	24.5	53.6	61.7	15.9
89	103.2	119.7	23.5	54.0	61.4	17.1
0.90	+104.1	+119.1	+22.5	−54.5	−61.0	+18.3
91	105.1	118.4	21.5	55.0	60.6	19.5
92	106.0	117.7	20.5	55.4	60.2	20.7
93	106.8	117.0	19.5	55.9	59.8	21.8
94	107.6	116.2	18.5	56.3	59.4	23.0
95	+108.4	+115.5	+17.5	−56.7	−58.9	+24.2
96	109.2	114.7	16.5	57.1	58.5	25.4
97	110.0	114.0	15.5	57.5	58.0	26.6
98	110.8	113.2	14.5	57.9	57.6	27.8
99	111.6	112.5	13.5	58.3	57.2	29.0

Table VII contains the computation of P from the early Potsdam observations by this procedure, which makes possible the use of each isolated early observation, and which assigns to each observation its appropriate weight in taking the mean.

TABLE VII.

Observer	t	V	τ	$t_0+\tau-t$	n	P
		km				
Vogel-Scheiner	$982^d.37$	− 8.8	$5^d.65$	$4815^d.41$	840	$5^d.7326$
	1008.34	+ 3.7	3.09	4786.88	835	5.7328
	1790.26	−55.0	5.04	4006.91	699	5.7323
	1791.26	+13.0	0.13	4001.00	698	5.7321

On summing up the numbers $t_0+\tau-t$ and n, we obtain

$$3072\ P = 17610^d.20$$
$$P = 5.7325$$

Deslandres' observations could not be used for a determination of the period, since the times of the observations were not exactly given by him; and this is also the case with the plates obtained with high dispersion in the years 1900 and 1901. The computation for the series in the winter of 1902–3 is given in Table VIII. The observations have been here omitted which would yield an uncertain value of τ on account of their position in the neighborhood of the points of inflection of the velocity-curve.

TABLE VIII.

Observer	t	V	τ	$t_0+\tau-t$	n	P
		km				
Hartmann	$6095^d.38$	−49.3	$5^d.14$	$298^d.11$	52	$5^d.7329$
	6096.37	+47.2	0.41	303.83	53	5.7326
	6098.46	+56.1	2.58	303.75	53	5.7311
	6124.34	−32.7	5.39	326.82	57	5.7337
	6127.39	+38.2	2.75	332.51	58	5.7329
	6128.34	−46.4	3.74	332.47	58	5.7322
	6153.37	0.0	0.00	361.24	63	5.7340
	6181.23	−54.9	5.04	384.06	67	5.7322

Hence

$$461\ P = 2642^d.79$$
$$P = 5.7327$$

On combining this with the previous result we finally get

$$3533\,P = 20252^{d}.99$$

whence follows the definitive value of the period of revolution

$$P = 5^{d}.7325 \pm 0^{d}.0002 \text{ or } 5^{d}\ 17^{h}\ 34^{m}\ 48^{s} \pm 17^{s}.$$

With the aid of the ephemeris, and using this value of the period, I now made a comparison of all observations with the computed orbit. For my own observations this comparison is contained in the last two columns of Table I. Some of the residuals $V-C$ are of very considerable size, in accordance with my remarks above as to the uncertainty of the measures. The mean error of one plate with Spectrograph I is found from the sum of the squares of the residuals to be $\pm$ 8.0 km. The uncertainty of the plates taken with higher dispersion is decidedly larger, as may be seen from the similar comparison for the other observers given in Table IX. I have put in reasonable estimates for the times of observations of Deslandres and Wright, which were not given exactly.

TABLE IX.

Observer	Date	Julian Day	V	C	$V-C$
			km	km	km
Vogel-Scheiner	1888, Dec. 10	$0982^{d}.37$	− 8.8	− 19.3	+10.5
	1889, Jan. 5	1008.34	+ 3.7	+ 27.5	−23.8
	1891, Feb. 26	1790.26	−55.0	− 49.0	− 6.0
	27	1791.26	+13.3	+ 48.0	−34.7
Deslandres	1899, Dec. 8	4997.42	+95	+102.8	− 7.8
	9	4998.42	−15	+ 2.1	−17.1
	12	5001.42	+70	+ 43.1	+26.9
	15	5004.42	−38	− 21.8	−16.2
	18	5007.42	+81	+ 75.3	+ 5.7
	1900, Jan. 9	5029.38	−37	− 31.6	− 5.4
	10	5030.38	+64	+ 78.8	−14.8
	12	5032.38	+80	+ 46.6	+33.4
	13	5033.38	−49	− 42.2	− 6.8
	18	5038.34	+14	+ 22.5	− 8.5
	25	5045.34	−50	− 63.9	+13.9
Wright	1900, Aug. 12	5244.98	+ 3	− 3.6	+ 6.6
	21	5253.96	+51	+ 80.0	−29.0
	Sept. 17	5280.92	−69	− 66.0	− 3.0

We see at once from the values of the last column that the precision of measurement was of the same order for all of the observers.

After completing the determination of the orbit, I made a further investigation as to the behavior of all the separate lines used for measuring the velocity. For this purpose I arranged in order, according to the orbital position of the star, all the velocities calculated from each separate line, as well as all the remarks which were noted as to the appearance of the lines during the measurement of the plates. It appeared in this way that the residual errors of the individual lines, as well as the unsymmetrical diffuseness, the apparent doubling, and similar phenomena, occurred at all points of the orbit without any evidence of regularity, so that no further conclusions could be drawn at this time on this subject.

It remains for me to discuss in a few words the effect of the velocity of light upon this determination of the orbit. This effect would in general involve three corrections: the first, known under the name of the equation of light, due to the periodic variation of the distance of the Earth from the observed star in the course of a year; the second, quite analogous, due to the distance changing periodically during the period P; and the third, due to the linear increase of the path of the light with the velocity V_0. In the case before us the first two of these equations are entirely negligible. The maximum effect of the equation of light on the *difference* of two times of observations amounts to $11^m\ 18^s = 0^d.0078$, and is therefore of a vanishing order, since all the times of observation were only given to $0^d.01$, corresponding to the accuracy of the measures. The same thing holds good for the light-equation in the orbit of the star, which reaches a maximum of $52^s = 0^d.0006$. But the third correction is, on the contrary, distinctly appreciable. In consequence of the increasing of the distance of the star with the velocity $V_0 = 23.1$ km, the period P appears to us longer by $38^s.02$ than the true period P_1, which accordingly is only $5^d\ 17^h\ 34^m\ 9^s.98 = 5^d.73206$. The above elements of the orbit, particularly $a \sin i$, were computed with this value of P_1.

It may be remarked in conclusion that the light of δ *Orionis* is suspected of variation. John Herschel believed he could detect a variation of the brightness, and the star has been since

then often observed, but with contradictory results. Auwers[1] established in 1854, and followed until 1858, a regular variation of the light with a period of $16^d.08$, which is nearly equal to three times the period found above. Later observers regarded the variations as only apparent and due to the difficulty of observing this star on account of its low altitude. It is, in any case, to be desired that as sharp as possible a series of photometric measurements should be made for the definitive settlement of the question. In case the star is partially eclipsed by its companion, and hence belongs to the Algol type, the approximate times of minima could be computed from the formula 1902, Feb. 14. $02 + nP$.

ASTROPHYSICAL OBSERVATORY, POTSDAM,
March 10, 1904.

[1] *Astronomische Nachrichten*, **50**, 103, 1859.

Minor Contributions and Notes.

STARS HAVING PECULIAR SPECTRA.[1]

An examination of the photographs of the *Henry Draper Memorial* has led to the discovery by Mrs. Fleming of a number of variable stars and objects having peculiar spectra, in addition to those previously published. A list of these has been compiled by Mrs. Fleming, and is given in the table, together with a number of other variables found as described in the remarks following the table. The constellation and catalogue designation are given in the first two columns. The approximate right ascension and declination for 1900, and the catalogue magnitude, are given in the third, fourth, and fifth columns. The class of spectrum, a brief description of the object, and the name of the discoverer are given in the sixth, seventh, and eighth columns. The designations for stars north of declination -23° are taken from the *Bonn Durchmusterung*, for stars between declinations -23° and -52° the *Cordoba Durchmusterung* is used, and for stars south of declination -52° the *Cape Photographic Durchmusterung* is used. Each of these variables has been confirmed independently by a second observer.

Constellation	Designation	R. A. 1900	Dec. 1900	Mag.	Spectrum	Description	Discoverer
Taurus	.....	$5^h46^m.9$	$+15^\circ\ 57'$	....	.....	Variable	W. P. Fleming
Auriga	$+42^\circ.1571$	6 27.6	+42 34	9.3	N.	Variable	W. P. Fleming
Canis Minor	.....	7 42.8	+ 5 44	....	.....	Variable	L. D. Wells
Vela	-46.3951	8 11.7	−46 10	7.1	B 3 A	*Hβ* bright	A. J. Cannon
Vela	-48.4658	9 20.4	−48 26	10.0	Md.	Variable	W. P. Fleming
Carina	.....	9 35.9	−59 38	....	Br. lines	Gaseous nebula	W. P. Fleming
Carina	-57.2781	10 8.3	−57 33	6.7	B 3 A	*Hβ* bright	W. P. Fleming
Carina	.....	10 32.8	−70 12	....	Md.	Variable	W. P. Fleming
Vela	-47.6614	11 8.6	−47 40	9.9	Pec.	Dark bands	W. P. Fleming
Ursa Major	$+58.1346$	11 51.3	+58 25	7.5	Md.	Variable	E. S. King
Crux	.....	12 50.7	−57 21	....	Pec.	Variable	W. P. Fleming
Centaurus	-56.5650	13 7.6	−56 26	9.4	.....	Variable	S. E. Breslin
Virgo	-18.3640	13 31.0	−19 5	9.0	.....	Variable	W. P. Fleming
Ara	-45.11383	17 11.6	−45 52	10.0	N.	Variable	L. D. Wells
Lyra	$+28.3055$	18 37.6	+28 43	9.3	Mc.	Variable	W. P. Fleming
Telescopium	-50.12918	20 12.9	−50 8	10.0	N.	Variable	L. D. Wells
Capricornus	-16.5558	20 13.3	−16 10	8.0	Mc.	Variable	W. P. Fleming
Cygnus	$+40.4393$	20 58.9	+40 54	8.4	.....	Variable	J. A. Dunne
Indus	-54.9810	21 3.1	−54 7	10.0	Pec.	Dark bands	W. P. Fleming
Cepheus	.....	22 12.9	+55 7	....	Br. lines	Type V	W. P. Fleming
Lacerta	.....	22 19.9	+50 28	....	Br. lines	Gaseous nebula	W. P. Fleming
Pegasus	.....	22 59.2	+14 45	....	.....	Variable	E. C. Pickering

[1] *Harvard College Observatory Circular* No. 76.

REMARKS.

h m

5 46.9 Found by comparison of photographic charts while identifying Anderson's variable star *Z Tauri*. Measures of one hundred and fifty-seven plates, taken between December 16, 1885, and April 24, 1903, show a variation in magnitude from 11.7 to 14.5.

7 42.8. An examination of twenty-two plates, taken between February 22, 1886, and February 19, 1903, shows a variation of about half a magnitude in the preceding and northern of two faint adjacent and nearly equal stars. This deviation although small, seems to be real, as sometimes one and sometimes the other is the brighter of the two stars. Their distance apart is about 25″.

8 11.7. Miss Cannon finds that the line $H\beta$ is bright in the spectrum of this star, and suspects that this line is variable.

9 20.4. Spectrum type III, having also the lines $H\delta$ and $H\gamma$ bright.

9 35.9. A very faint gaseous nebula.

10 32.8. Spectrum Type III, having also the lines $H\delta$ and $H\gamma$ bright.

11 8.6. In the spectrum of this star a strong dark band extends from about λ 465 to 471. This band seems to have the same wave-length as the strong bright band in *H.P.* 1311, and similar spectra of Type V.

11 51.3. Found from peculiarity of its spectrum, which is of Type III, having also the lines $H\delta$ and $H\gamma$ bright. An examination of twenty-two plates, taken between November 9, 1897, and March 13, 1904, shows a variation of at least 1.5 magnitudes.

12 50.7. In the spectrum of this star a strong dark band extends from about λ 465 to 471, and it closely resembles the spectrum of $-47^{\circ}6614$, except that the lines $H\gamma$ and $H\beta$ are bright. No other star has, so far, been found showing these peculiarities in its spectrum.

13 7.6. Found from photographic charts, while measuring magnitudes of — *Centauri*, $-56^{\circ}5632$. It was originally the comparison star *n* for this variable.

13 31.0. Found by comparison of photographic charts while looking for asteroid found on Plate A 3078, taken on June 8, 1898.

17 11.6. An examination of nine plates, taken between June 24, 1893, and June 20, 1901, shows a variation of about 1.0 magnitude.

18 37.6. An examination of eighteen photographic charts, taken between July 21, 1892, and May 1, 1903, shows a variation of about 0.8 magnitude.

20 12.9. An examination of ten plates, taken between August 25, 1889, and July 30, 1902, shows a variation of about 0.7 magnitude.

20 58.9. Found in 1901, by Mr. Dunne, from observations with the meridian circle. An examination of nineteen plates, taken between November 6, 1889, and July 12, 1900, shows a variation of about 1.0 magnitude.

21 3.1. The spectrum of this star is similar to that of $-47^{\circ}6614$, mag. 9.9, mentioned above, and *Z. C.* 18^{h} 1935, mag. 9. These three are the only stars, so far known, which have this spectrum.

22 19.9. A spectrum plate, taken with the eight-inch Draper Telescope on December 18, 1903, shows the spectrum of this faint gaseous nebula superposed on that of $+50^{\circ}3007$, magnitude 9.4, which is of class A.

22 59.2. Found from comparison of chart plates. Measures of sixty-nine plates, taken between November 23, 1889, and January 19, 1901, show a variation in magnitude from 8.8 to 12.2.

In a photograph taken with the eight-inch Bache telescope on July 15, 1898, the variable star *RS Ophiuchi* has a spectrum of the third type in which the lines $H\zeta$, $H\epsilon$, $H\delta$, $H\gamma$, $H\beta$ are bright, the estimated relative intensities of these lines being about 2, 1, 5, 10, and 20, respectively. Two bright lines, intensities 7 and 14, are also present. They appear to coincide with the bright lines in γ *Velorum*, whose wave-lengths are 4656 and 4691. No other variable star having this type of spectrum has hitherto been found.

EDWARD C. PICKERING.

MARCH 21, 1904.

VARIABLE STARS IN THE NEBULA OF *ORION*.[1]

THE Great Nebula of *Orion* has been the subject of careful study by astronomers for many years. Volume 5 of the *Annals* of the Harvard Observatory contains an elaborate discussion of this nebula, by Professor Bond, including a comparison of the material previously collected. Many stars in it have been announced as variable, but strangely enough the changes in only one of them, *T Orionis*, have been generally admitted. In 1901, and again in 1903, Professor Wolf, of Heidelberg, compared several of his photographs by means of stereo-comparators and announced a number of variables in this part of the sky. They do not appear to have been confirmed by other observers, and final designations have not yet been assigned to them. The faintness of many of these stars even at maximum renders it probable that comparatively few photographs exist on which they can be followed. A grant made by the Carnegie Institution for 1903 permitted a large amount of work of this kind to be undertaken here, and furnished a corps of eight observers for the study of the Harvard photographs. The failure to continue this grant for 1904 rendered it necessary to disband this corps, and since December 1903 similar work has been carried on, at the expense of the observatory, by only one observer, Miss Henrietta S. Leavitt. A number of photographs of the nebula of *Orion*, having long exposures, are contained in the Harvard collection, and a careful examination of them has been made by Miss Leavitt. Besides confirming sixteen of Wolf's variables, she has found many new ones, which renders it probable that nebulæ as well as clusters may furnish fruitful fields for the discovery of such objects. Three plates taken with the thirteen-inch Boyden telescope were examined, the first made on September 15, 1893, exposure 180^m; the second on September 17 and 18,

[1] *Harvard College Observatory Circular* No. 78.

1893, exposure 480^m; and the third on December 5, 1893, exposure 151^m. Plates taken with the twenty-four-inch Bruce telescope, on January 8, 1894, exposure 60^m; January 25, 1894, exposure 60^m; January 27, 1895, exposure 180^m; October 6, 1896, exposure 180^m; November 9, 1896, exposure 123^m; November 10, 1896, exposure 265^m; December 17, 1898, exposure 60^m; December 3, 1901, exposure 60^m; and December 4, 1901, exposure 420^m, were also used. For stars which, on plates having long exposures, are deeply involved in nebulosity, an examination was also made of plates taken with the thirteen-inch Boyden telescope on September 12, 1893, exposure 10^m, and on March 13, 1896, exposure 10^m, and of plates taken with the twenty-four-inch Bruce telescope on November 30, 1893, exposure 61^m; December 27, 1893, exposure 60^m; January 1, 1894, exposure 11^m; January 1, 1894, exposure 60^m; October 29, 1897, exposure 10^m; and December 8, 1898, exposure 10^m. Some excellent photographs taken with the eight-inch Bache telescope in 1888 (*Annals* **18**, 114) can be used only for the brighter variables. So far as possible, the map and catalogue of Bond (*Annals*, **5**) were used to locate these stars, and their positions were derived by adding the co-ordinates given by Bond to those of θ^1 *Orionis*, whose position for 1900 is assumed to be R.A. $= 5^h\ 30^m\ 21^s.3$, Dec. $= -5^\circ\ 27'.3$. Estimates were made of the positions of stars not in this catalogue, and are given to seconds of time in right ascension, and to tenths of a minute of arc in declination.

A provisional scale of magnitudes was used which is fairly comparable with that of Wolf. On this scale, the faintest stars seen on Plate 26 of Roberts's *Photographs of Stars, Star Clusters and Nebulæ* have the magnitude 14.8. The original negative was taken with his twenty-inch reflector on January 15, 1896, and had an exposure of 90 minutes. The faintest stars shown in Plate XXIII of Volume **2** of the *Publications of the Yerkes Observatory* have the magnitude 15.5. The original negative was taken with the twenty-four-inch reflector on October 19, 1901, and had an exposure of 60 minutes.

A list of the stars certainly variable is given in Table I. Those found by Wolf have been confirmed by Miss Leavitt. Those found by Miss Leavitt have been examined by Mrs. Fleming, on several plates, and the variability in each case confirmed. Although the changes in some of these stars are small, they seem to be real, since, owing to their faintness, good comparison stars can be found near them. A number for reference, the provisional designation given to Wolf's stars in the *Astronomische Nachrichten*, **163**, 161, the number in the catalogue of

TABLE I.

Stars Certainly Variable.

No.	Designation	Bond No.	R. A. 1900	Dec. 1900	Harvard		Heidelberg	
					Br.	Ft.	Br.	Ft.
1	.....	...	$5^h27^m\ 53^s$	$-5°44'.0$	14.1	<15.5	....	....
2	.....	...	28 27.	−5 26.1	14.5	<15.1	....	....
3	36.1903	...	28 37.	−5 16.1	14.4	14.9	13.8	15.0
4	.....	...	28 37.	−4 47.6	14.0	15.0	....	....
5	.....	173	28 37.0	−4 48.2	13.9	14.6	....	....
6	.....	...	28 40.	−5 5.7	13.3	14.6	....	....
7	.....	...	28 47.	−6 22.8	12.5	<15.5	....	....
8	.....	...	28 54.	−6 44.3	13.2	15.5	....	....
9	.....	...	28 59.	−5 45.8	13.2	14.1	....	....
10	37.1903	...	29 0.	−4 52.0	13.8	15.2	13.0	15.2
11	.....	...	29 5.	−6 40.3	13.7	<15.5	....	....
12	.....	276	29 8.7	−5 41.1	12.9	14.0	....	....
13	.....	288	29 12.2	−5 17.8	12.9	14.2	....	....
14	.....	...	29 15.	−4 54.1	14.5	15.2	....	....
15	.....	...	29 21.	−5 8.6	14.3	<15.0	....	....
16	38.1903	...	29 24.	−6 40.0	11.4	14.1	13.0	15.0
17	.....	...	29 29.	−5 35.0	13.5	14.8	....	....
18	.....	...	29 31.	−4 49.5	14.9	15.5	....	....
19	.....	417	29 42.8	−6 9.6	13.4	14.5	....	....
20	.....	419	29 43.0	−5 39.0	14.1	14.6	....	....
21	.....	435	29 46.0	−5 26.8	12.1	12.7	....	....
22	.....	...	29 47.	−5 50.1	14.2	15.5	....	....
23	.....	...	29 49.	−5 14.8	14.2	15.5	....	....
24	.....	481	29 54.8	−6 2.0	11.8	12.8	....	....
25	39.1903	484	29 55.1	−4 44.2	14.0	14.6	12.5	14.0
26	40.1903	509	30 1.6	−5 50.6	13.2	13.9	12.5	14.0
27	.....	511	30 2.1	−5 45.7	13.4	14.0	....	....
28	.....	...	30 2.5	−6 27.9	13.1	14.0	....	....
29	.....	520	30 4.3	−5 58.6	14.1	14.9	....	....
30	.....	...	30 5.	−4 54.8	12.7	13.1	....	....
31	.....	...	30 12.	−5 40.3	12.9	14.7	....	....
32	.....	561	30 12.2	−4 31.7	12.2	14.6	....	....
33	.....	...	30 13.	−5 41.1	14.1	15.0	....	....
34	41.1903	582	30 16.3	−5 50.5	12.1	13.0	12.0	14.5
35	42.1903	596	30 18.2	−4 49.7	13.0	13.7	12.7	<14
36	.....	606	30 19.5	−5 47.2	12.7	13.7	....	....
37	.....	620	30 20.7	−5 43.2	12.7	13.1	....	....
38	.....	...	30 21.	−5 56.1	13.8	14.6	....	....
39	.....	...	30 24.	−4 57.8	14.2	14.9	....	....
40	.....	668	30 25.5	−4 46.2	12.4	13.0	....	....
41	43.1903	680	30 26.8	−5 38.6	12.9	14.0	12.3	<14
42	.....	695	30 30.1	−5 13.7	11.1	12.5	....	....
43	.....	703	30 31.0	−5 15.0	11.8	13.2	....	....
44	.....	709	30 31.5	−5 29.6	10.7	11.3	....	....
45	.....	...	30 34.	−4 59.1	13.2	14.3	....	....
46	83.1901	756	30 40.0	−5 5.1	11.6	14.2	11.8	13.2
47	50.1903	758	30 40.1	−6 49.2	13.4	14.6	12.5	<14
48	.....	759	30 40.3	−5 25.5	13.0	13.6	....	....
49	.....	784	30 47.2	−5 32.1	10.3	11.0	....	....

TABLE I — *Continued.*

No.	Designation	Bond No.	R. A. 1900	Dec. 1900	Harvard		Heidelberg	
					Br.	Ft.	Br.	Ft.
50	.....	788	$5^h 30^m 47^s.3$	$-5° 9'.7$	14.0	<15.2	....	....
51	.....	...	30 52.	−5 5.1	14.4	15.0	....	....
52	.....	817	30 54.0	−5 53.5	14.1	14.8	....	....
53	.....	822	30 55.6	−5 32.4	....	....	....	....
54	44.1903	...	30 57.	−4 51.1	13.3	<15.0	12.8	<15
55	.....	838	30 58.1	−5 8.0	12.3	13.3	....	....
56	.....	...	31 0.	−6 25.5	14.1	14.7	....	....
57	45.1903	...	31 1.	−6 54.8	14.5	15.4	12.5	15.0
58	.....	...	31 9.	−4 45.5	14.0	14.8	....	....
59	46.1903	877	31 9.2	−6 46.5	13.0	14.9	12.6	<14
60	.....	885	31 13.8	−6 18.2	12.8	13.9	....	....
61	.....	...	31 16.	−6 52.0	14.4	<15.4	....	....
62	.....	...	31 18.	−6 33.3	13.7	<15.0	....	....
63	85.1901	908	31 21.4	−5 15.4	11.5	12.1	11.8	<14
64	.....	...	31 28.	−6 21.5	13.0	14.5	....	....
65	.....	951	31 42.7	−5 29.9	13.5	14.6	....	....
66	.....	...	31 46.	−6 23.1	12.1	13.3	....	....
67	.....	1009	32 8.8	−6 37.1	11.5	<14.8	....	....
68	.....	...	33 3.	−7 1.2	13.7	14.4	....	....
69	86.1901	...	34 46.1	−3 28.6	13.5	14.4	11.7	13.0
70	.....	...	35 13.	−6 18.9	12.2	13.2	....	....
71	49.1903	...	36 36.0	−4 11.3	10.5	<14.8	9.8	<15

Bond, the right ascension for 1900, and the declination for 1900 are given in the first five columns. The brightest and faintest magnitudes on the Harvard and Heidelberg photographs are given in the next four columns.

REMARKS.

3. Although the observed range is small, the variation is very clearly marked.

4, 5. The variation of these adjacent stars is marked.

6. Period apparently short.

12. Period apparently short.

13. Period apparently short.

18. This star, although faint, gives distinct images on the plates, and the variation is well defined.

20. The variation of this star, though small, is well shown by a comparison with three neighboring stars of about magnitude 14.5.

28. Bond 528 and Bond 537, the stars nearest this position, are wrongly charted on Bond's map. The position has, therefore, been determined independently.

30. The variation is obvious when different photographs are compared, but the strong nebulosity in the region of this star makes measurements of the magnitudes difficult.

37. The variation is small, but readily observed, as the variable is sometimes brighter and sometimes fainter than Bond 605, which precedes it $1^s.2$, and is in the same declination.

44. This star was suspected of variability by Holden.
47. Wolf announced this star as probably variable.
49. This star was suspected of variability by Schmidt.
51. Although this is a faint variable, it is easily observed. A star of about the fifteenth magnitude follows and is slightly south of it.
53. *7 Orionis.* This star was not measured, but the variation is obvious, on the plates examined.
63. No marked variation was found in this star, which was observed with some difficulty.
64. This star is on Bond's chart, but not in the catalogue.
66. This star is on Bond's chart, but not in the catalogue.
68. This star precedes the position given by Wolf of 47.1903, 35^s, and is north of it $18'$.
70. This star precedes the position given by Wolf of 53.1903, 26^s, and is north of it $10'$.

A list of stars suspected of variability is given in Table II, in the same form as Table I, omitting the last four columns. All of Wolf's stars may prove to be variable, but some are included in Table II, since they have not yet been confirmed here.

TABLE II.

Suspected Variables.

No.	Designation	Bond No.	R. A. 1900	Dec. 1900	No.	Designation	Bond No.	R. A. 1900	Dec. 1900
1	80.1901	...	$5^h 24^m 47^s.0$	$-8° 5'.2$	19	.....	...	$5^h 30^m 37^s.$	$-4° 52'.8$
2	32.1903	...	26 59.2	−4 31.4	20	.....	801	30 51.0	−5 32.0
3	33.1903	...	27 13.6	−5 7.1	21	.....	833	30 57.3	−5 55.6
4	34.1903	...	27 16.6	−7 32.8	22	.....	...	30 59.	−5 30.3
5	35.1903	...	27 54.0	−7 38.8	23	84.1901	...	31 0.4	−5 0.8
6	.....	216	28 50.5	−5 35.3	24	.....	...	31 5.	−6 1.3
7	81.1901	...	28 54.0	−4 42.8	25	.....	...	31 37.	−5 20.8
8	.....	...	29 15.	−5 36.3	26	51.1903	...	32 18.4	−3 35.2
9	.....	361	29 29.1	−5 1.1	27	.....	...	33 3.	−4 16.8
10	.....	492	29 56.8	−5 7.5	28	47.1903	...	33 38.4	−7 19.2
11	.....	...	30 0.	−6 33.5	29	52.1903	...	34 31.9	−4 57.4
12	.....	524	30 5.2	−5 27.0	30	87.1901	...	35 10.1	−5 24.4
13	.....	527	30 5.6	−5 48.5	31	53.1903	...	35 39.4	−6 29.0
14	.....	558	30 10.7	−5 29.3	32	48.1903	...	35 57.8	−8 8.5
15	.....	...	30 14.	−5 35.5	33	54.1903	...	35 57.9	−8 7.7
16	.....	...	30 17.	−5 34.5	34	88.1901	...	42 27.9	−6 14.8
17	.....	...	30 25.	−5 35.3	35	89.1901	...	43 16.1	−5 43.6
18	82.1901	...	30 36.8	−6 7.1					

REMARKS.

1. The region is on the extreme edge of the plates examined. No variation was detected in any star near the position announced.
2. No star near this position was found to vary with certainty. A fourteenth magnitude star was suspected of being unduly faint on January 8, 1894, and on January 27, 1895.

3. No variation could be found in any star near this position. Probably the variable remains faint during the greater part of the time, as it was seen bright on only one of the Heidelberg plates.
4. A star of about the magnitude 14.5 in this position appears to fluctuate slightly in brightness, but no conclusive evidence of variation has been found.
5. No variation was found in any star near this position.
7. Assumed to be Bond 223. On the plates examined the star is always of about the magnitude 13.5. No star near this position has been found to show variation.
14. This star is in a strongly nebulous region and the variation is possibly only apparent.
18. The star nearest the position is Bond 745, which does not show variation on the plates examined. On each of them it is of about the magnitude 13.5.
20. Bond considered this star to be variable. There appears to be some fluctuation in light, but on the plates examined the evidence of variability is not conclusive.
23. Bond 844 is in the position given. On all the plates examined, the light remains at about the magnitude 13.7.
26. No variation was found in any star near the position given.
28. A star near this position appeared to be nearly half a magnitude fainter than usual on December 17, 1898. The images of stars in the vicinity are poor, however, and the evidence of variation does not appear to be conclusive. See remark on No. 68 in Table I.
29. The star nearest the position given shows some evidence of variation. On the plates the brightness appears to be constant. On January 8, 1894, and January 27, 1895, the star appears nearly half a magnitude fainter than usual, but the images are poor in each case.
30. Of the two stars near this position, the southern always appears about two-tenths of a magnitude the brighter, except on the plates taken November 9, 1896, and December 3, 1901. On these plates the two stars appear equal.
31. No star near the position given shows variation on the plates examined. See remark on No. 70 in Table I.
32. The region is covered by only three of the plates examined, and on them the star is too near the edge for accurate observation. The northern of two faint stars near this position was suspected of being half a magnitude brighter on November 10, 1896, than on November 9, 1896. The two stars are doubtless Wolf's 48.1903 and 54.1903.
33. See remark on No. 32.
34. The region is on the edge of the plates examined. No star could be found showing the progressive diminution of light announced by Wolf.
35. The region is on the extreme edge of the plates examined. No star near the position was found to show variation.

The region covered in this examination was that of Bond's map, which extends between the limits preceding and following θ^1 *Orionis* by $2^m\,42^s$, and from 87′ north of this star to 91′.5 south of it. The corresponding limits for 1900 are R. A., $5^h\,27^m.7$ to $5^h\,33^m.1$, Dec., $-4°\,0'$ to $-6°\,59'$. The area of this region is 14,458 square minutes of arc, and the number of stars examined about 3,000. A small region

near the announced position of each of Wolf's variables, situated beyond the limits of the map, was also examined.

The distribution of the variables contained in Table I emphasizes their close connection with the nebula. They are found principally in a narrow region on each side of a line extending southward from c *Orionis* through θ and ι, and beyond. North of declination $-4^{\circ}44'$ only one variable was found out of about 900 stars examined. Within the limits of the remainder of Bond's map, out of 550 stars examined, only one variable has been found preceding R. A. $5^{h}\,28^{m}.4$, and out of 450 stars examined, only one variable has been found following R. A. $5^{h}\,31^{m}.8$. The areas of these three regions are 3524, 1417, and 2632 square minutes of arc, respectively. In the remaining region, covering 6885 square minutes, out of about 1,100 stars examined, 65 have been found to be certainly variable, and 20 more are probably variable. A suspicion is also attached to several other stars not here announced.

It is not improbable that other variables may be discovered when more photographs become available for comparison, as many of those found appear to be of the same class as the variables in globular clusters which remain at their minimum magnitude during a large part of the time. Those of Wolf's variables which were not confirmed upon the Harvard plates may belong to this class.

EDWARD C. PICKERING.

MARCH 23, 1904.

Reviews

Handbuch der Spectroscopie. Von H. Kayser. Zweiter Band. Leipzig: S. Hirzel, 1902.

The very exceptional interest and importance of the second volume of Kayser's great *Handbuch* seemed to call for an extended critical review, which might do the book some measure of justice. Unfortunately, the pressure of other duties has left insufficient opportunity for such a task, and the passage of time gives warning that another volume may be forthcoming before mention has been made of its predecessor. For this reason it seems preferable to publish even an inadequate reference to the present volume now, rather than to wait longer for a better opportunity. So far as the importance of the book goes, it is quite unnecessary to speak. Every spectroscopist knows that here is the one source in which he may find a full and critical discussion of the literature of his subject. Not only does this include references to practically every work of importance, but we also find a careful summary of the results of each research, in which all important points are brought out and accompanied by critical remarks from one of the best living authorities on spectroscopic subjects. Professor Kayser rarely fails to discover the weak point of a paper, whether it be in the methods of observation or in the discussion of the results. At times he is perhaps a severe critic, but his criticisms are based upon sound and careful reasoning, and almost invariably command the reader's approval.

The first volume of the *Handbuch*, with its admirable description and critical account of spectroscopic instruments, has doubtless been a chief book of reference to all spectroscopists since the time of its appearance. The second volume deals with a wide range of subjects, and is even more fascinating than the first. Here we find chapters on emission and absorption, the radiation of solid bodies, the radiation of gases, the spectra of compounds and multiple spectra, the influence of temperature, pressure, and the nature of the electric discharge on spectra, the widening and reversal of spectra lines, Doppler's principle, spectral series, and radiation in the magnetic field. The chapter on Doppler's principle is by Professor Kayser's assistant, Dr. H. Konen, while that on the Zeeman effect is by Professor Runge. It would be

an agreeable task to analyze carefully the contents of the book, and to discuss many of the interesting questions which it raises; but we must content ourselves with a few remarks on certain points which seem to call for special mention. It ought to be said that these are taken more or less at random, and by no means cover the most important portions of the book.

At the present time few subjects in spectroscopy are of greater interest than the applicability of Kirchhoff's law to the solution of solar and stellar problems. The law requires that the radiation must be due to heat alone, and when this condition is not met, conclusions based upon the law may be invalid. We find many cases to which it seems impossible to apply the law directly, *e. g.*, that of the calcium vapor in the flocculi, which appears to increase in radiating power as it rises above the photosphere, until it attains a maximum at some point below the upper limits of the chromosphere. Hydrogen in the flocculi offers another most interesting case, in which one is tempted to believe at least that the law is sufficiently obeyed to permit the conclusion that the bright hydrogen flocculi are actually hotter than the dark ones. But if mystery still attaches to such phenomena, it must not be forgotten that the law seems to be capable of explaining certain appearances, such as the simultaneous presence of dark and bright hydrogen lines in the spectrum of a star, which have sufficed to puzzle able observers. This point, together with many others of equal interest, is discussed by Professor Kayser in the first chapter of his volume, which contains Kirchhoff's original statement of the law in slightly modified form, together with both qualitative and quantitative proofs of the law and Paschen's quantitative proof for gases. To the astrophysicist the summary in the second chapter of the remarkable recent advances, both experimental and theoretical, in our knowledge of the radiation of solid bodies will be of special importance in connection with the determination of the Sun's temperature. The extravagant values of the solar temperature reached by early investigators were due almost entirely to the use of incorrect radiation formulæ, and recent determinations, based upon more reliable formulæ, agree far better among themselves. The work described in this chapter, and also, indeed, in every other chapter of the book, affords striking illustration of the dependence of the astrophysicist upon the experimental and theoretical investigations of the physicist, with whose work he cannot be too familiar. From an experimental standpoint, one of the most important advances of recent years has been the realization in the laboratory of a

perfectly black body. This principle has already found practical application in the construction of bolometers, as well as in other departments of investigation.

The chapter on the radiation of gases opens with a confession of our almost total ignorance of the source of the energy which constitutes light, and the nature of the transformation of this energy into light. It is an excellent plan to bear constantly in mind, as Professor Kayser insists that his readers shall do, that the nature of the discharge in vacuum tubes and in the spark, for example, is almost wholly unknown; whence the danger must be obvious of applying conclusions based upon the study of these phenomena in the explanation of other and even more mysterious phenomena. Kayser believes, as Rowland was inclined to do, that the phenomena of the electric arc are to be regarded as more truly thermal than electrical, while the complex phenomena of the spark are to be considered as involving less of distinctly thermal influence. Rowland's almost exclusive use of the arc in his spectroscopic work was due to a desire to avoid the complications inevitable when the high potential discharge is employed. Kayser also gives the necessary weight to radiation resulting from chemical processes, and to the phenomena of fluorescence and phosphorescence. It is interesting to note that, while Kayser believes that a considerable part of the energy emitted by flames is the direct result of chemical processes, he nevertheless thinks that the spectra of all gases could be produced by heat alone, if sufficiently high temperatures were available. This is a point of special interest, since it is constantly appearing in discussions of solar and stellar phenomena.

Chapter IV contains an extended critical discussion of Lockyer's dissociation hypothesis, in which both the weak and the strong points in Lockyer's arguments are clearly pointed out. After quoting Schuster's views, Kayser expresses his conviction "that in general the spectrum of an element is compounded of numerous spectra, which belong to variously constructed molecules; the majority of the molecules will correspond to the degree of dissociation given by various controlling conditions at the time — temperature, pressure, quantity of dissociated and undissociated molecules, manner of excitation. But we always have a number of molecules which correspond to greater and less degrees of dissociation, the number of which diminishes the farther they are from the mean condition. For each substance there is a definite temperature at which it is completely dissociated, and this condition will be the more easily reached the simpler the molecule and

the lower its melting-point." It will thus be seen that Kayser shares Lockyer's general views, though he does not follow him in many of his conclusions. He is ready to accept the view that at very high temperatures the elements may be broken up into parts which give different spectra, but he refuses to follow Lockyer when he contends that these constituent parts are common to different elements.

It would be interesting to examine Kayser's discussion of the various arguments advanced by Lockyer in favor of the dissociation hypothesis. Kayser points out the weakness or total failure of the arguments based on the supposed absence of metalloids from the Sun; the supposed existence of lines common to two or more elements ("basic lines"); the faulty interpretation of experiments involving the distillation of magnesium and other vapors; the assumption that certain carbon bands may appear alone, and mark different degrees of dissociation, whereas they in reality are due to cyanogen, and always appear together; the assumption that hydrogen given off by heating such elements as sodium and lithium is due to dissociation, when in fact it is simply occluded gas. He is inclined to attach more weight, however, to the variation of the intensity of the 4227 and H and K lines of calcium under different conditions, though he is careful to refer to the effects obtained by Huggins in varying the density of the calcium vapor. Kayser seems to think Lockyer's strongest arguments are those derived from his studies of solar and stellar spectra, and remarks that at these very high temperatures dissociation would be much more probable. In this connection he discusses the question of basic lines in spots and prominences, the different distortion of different lines of the same element (which Kayser considers as a proof of dissociation), the change of the widened lines in spots during the transition from the maximum to the minimum period, and the question of enhanced lines in the spectra of stars and the chromosphere. The fact that different lines of the same element are not always similarly affected in solar eruptions is exceedingly important, but it would be well to reserve conclusions until this question has been given a thorough investigation with modern instruments. The same may be said of the question of widened lines in Sun-spots, since Lockyer's plan of recording only a few of the most widened lines, with instruments not sufficiently powerful to remove all doubts as to identification, is undeniably faulty. As for enhanced lines in stellar spectra, some of Lockyer's recent results are certainly most interesting and suggestive, but here again an important difficulty remains through the possible confu-

sion of electrical effects with those of temperature alone. In spite of the apparent evidence in favor of dissociation, resulting from recent investigations of the Zeeman effect; the effect of pressure on wave-length; the existence of the second series of hydrogen in certain stars; the different behavior of different lines of the same element under change of self-induction; the apparently different velocities corresponding to different lines of the same element, as observed by Schuster in measuring the speed of the particles shot off from the poles in an electric discharge; the experiments of Thomson on the breaking up of the hydrogen atom; and the emission of helium by radium; it is probable that many spectroscopists will prefer to reserve judgment for the present, even though they may be inclined to believe that dissociation offers the simplest means of explaining a large number of phenomena.

Chapter v, on the influence of pressure, temperature, and the nature of the electric discharge on spectra, is an exceedingly interesting discussion of the literature of these subjects. Chapter vi deals with the widening of spectral lines, and with single and multiple reversals. Chapter vii gives an excellent account of Doppler's principle, dwelling, however, upon the physical elements of the problem, and referring only briefly to its astronomical applications. Chapter viii is a most valuable account of the subject of spectral series, including all of the exceedingly important work done in this field during recent years. The volume concludes with Professor Runge's chapter on radiation in a magnetic field, which constitutes the most valuable discussion of this subject hitherto published.

Even from this brief mention of some of the principal contents of the volume, it will be seen that the work of every spectroscopist must be greatly facilitated by having the book constantly at hand. The suggestions as to problems which still require investigation are most valuable, and may be especially commended to those who are seeking subjects for research. When the five volumes of the *Handbuch* have been completed, they will form a library of spectroscopy the importance of which it would be difficult to overrate.

G. E. H.

Light Waves and Their Uses. By A. A. Michelson, The University of Chicago Press, 1903. Pp. 166, with 108 figures in text and three colored plates. Price, $2, *net.*

The title of this book, taken in conjunction with the name of its author, leads one to suppose, even before reading it, that it deals

mainly with interference phenomena, and particularly with the many interesting applications of the interferometer. The author apologizes for describing so many of his own experiments, offering the very satisfactory excuse that he is more likely to make the subject interesting by doing so than by giving accounts of the work of others.

The book is based on eight lectures given at the Lowell Institute in Boston in 1899. Probably the most serious criticism that can be brought against it is that many of the more elementary explanations and definitions are too brief to be readily understood by the general reader, for whom they were intended. This is the case with such concepts as "phase," "simple harmonic motion," etc. The transition from the telescope or microscope to the interferometer is also rather confusing, and indeed it is hard to see that anything is gained by such a conception of essential similarity in instruments so unlike.

Apart from a few such matters, there is little to criticise and much to commend; and the hope expressed in the preface, that "some of the ideas may be of interest to physicists and astronomers," proves to be well founded.

The first lecture deals with the wave theory of light, and particularly with interference phenomena, the colors of thin films, and the lengths of the waves for different colors. The second treats of diffraction through openings of different shapes, and the resolving power of telescopes and microscopes, and introduces the interferometer.

In Lecture III the corpuscular theory is spoken of, and the crucial question of the relation between the velocity of light in air and that in a denser medium, as well as the solution of this question by the determination of both velocities in the laboratory. This brings up the subject of refractive indices, for the determination of which the interferometer is particularly suitable. Other applications are given, such as the determination of coefficients of thermal expansion, the testing of precision screws, and the measurement of wave-lengths.

Lecture IV is concerned chiefly with the method of visibility curves, as applied to the analysis of spectral lines which are usually considered monochromatic. Incidentally a short but interesting account of the harmonic analyzer is given.

Lecture V is devoted entirely to the measurement of the standard meter in terms of the wave-lengths of cadmium lines, and this is one of the most interesting parts of the book.

Lecture VI starts out with the Zeeman effect and the results obtained with the interferometer, using the visibility curve method.

In the latter half there is given an elementary explanation of grating spectra, and the limitations of the grating which led to the invention of the echelon spectroscope. Many will disagree with the statement on page 126 that the latter has all the advantages of the grating in addition to greater resolving power.

Lecture VII is on the application of interference methods to astronomy, particularly the increase of resolving power obtained by putting a pair of movable slits over the objective, or a movable system of mirrors. The principal applications are to close double stars and very small disks, as of asteroids or satellites; but the possibility of determining the diameters of fixed stars is also claimed.

The last lecture, under the title "The Ether," deals principally with the aberration problem, and the experiments carried out by Fizeau and by Michelson and others to explain the observed anomalies.

Altogether this book is of great interest to many besides the general reader, particularly as it gives a clear résumé of researches where in some cases the original papers are not readily accessible.

H. M. R.

Wellenlängen-Tabellen für spektralanalytische Untersuchungen, auf Grund der ultravioletten Funkenspektren der Elemente. Von FRANZ EXNER und E. HASCHEK. Theil I, pp. 83; Theil II, pp. 269. Leipzig und Wien: Franz Deuticke, 1902. 16 Marks.

TEN years ago the complaint could justly be made that the measurements of celestial spectra had been carried to a higher degree of precision than those upon spectra observable in the laboratory. This deficiency has been gradually remedied during recent years, so that the advance can be pushed in the quantitative work on the spectra of celestial bodies, which work must obviously depend upon the foundations established in the laboratory. Each additional table of wave-lengths accurately determined is to be welcomed, and with the acknowledged limitations of present methods of spectroscopic research there seems little danger of waste of effort in the duplication of measurements of wave-lengths of the lines of the elements, as produced under different conditions in the arc, spark, or other source.

The present tables differ from other contemporaneous measurements chiefly in the manner in which they were obtained. The authors employ the objective method of projecting upon a scale on a screen

an image of the negative, which was taken with a Rowland concave grating (of 15 feet radius, with 20,000 lines to the inch). A description of the method has already been given by Dr. Karl Kostersitz in this JOURNAL.[1] Wave-lengths are read off (only a single reading was made) directly on the scale, which is adjusted to its proper position with the aid of standard comparison lines of iron photographed immediately after the exposure of the element under investigation. Sufficient testimony as to the convenience and rapidity of this procedure is given by the fact that these tables, comprising the violet spark spectra of practically *all* of the elements, were produced in less than two years. Rowland's wave-lengths were used for the standard lines.

The authors devote some space in their introduction to a discussion of the accuracy of measurement attained by them in this work, and they conclude that the method stands on an equality in this respect with the usual process of measuring with a comparator and microscope. This will doubtless be questioned. The errors due to optical distortion in the projection apparatus are likely to be more serious than in case of a comparator, where the settings are commonly made at the same central point in the field. It is, furthermore, obvious that the defects in the definition of the lines on the negative, whether due to improper exposure or poor focus, will have their effect on the reading quite as seriously as in case of the comparator, and the advantage is lost of the repetition of the settings, unprejudiced by a knowledge of the reading on the micrometer head. The authors contented themselves with an accuracy averaging about 0.015 tenth-meters, considering it undesirable to go beyond this on account of the "shifts" which they observed in the case of many lines. A criticism of the reality of these supposed displacements by Messrs. Eder and Valenta appears elsewhere in this number, and will doubtless tend to diminish the reader's confidence in the accuracy of these wave-lengths of Messrs. Exner and Haschek. However, even if the precision of the results in these tables may be considerably less than the authors have estimated, their value to the physicist, chemist, and astronomer is nevertheless great, on account of their comprehensiveness, convenience of arrangement, and compactness.

The tables are comprised in three parts: (1) a list of the principal spark lines of each of the elements, which are arranged in alphabetical order, with estimates of the intensities of the lines (for iron thirty-five such lines are given); (2) a list, in order of wave-length, of the

[1] **16**, 262–264, November 1902.

chief lines of all the elements, with the symbol of the element in which a line is found. This should be of service where it is desired to trace the origin of a conspicuous line, or to find what element will produce a line near a desired wave-length. This list occupies fifty-two pages, but in practice is likely to be found too incomplete rather than too full. (3) The complete list, for the region covered, from about λ 2100 to 4700, of the measured wave-lengths of all the spark lines observed by the authors, arranged by elements in alphabetical order. This constitutes *Theil II* of the work. References are given under each element to the other recent measurements by other investigators.

The tables are printed in large, clear type without waste space, on a page 18 × 12 cm in size. They will assuredly serve a useful purpose, even if the individual wave-lengths are not accepted as up to the standard of the highest accuracy now attainable. E. B. F.